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None

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UK CL (Edition V) **E1F** FLA
INT CL^7 **E21B**
Other: **Online: WPI, EPODOC, JAPIO**
updated as appropriate

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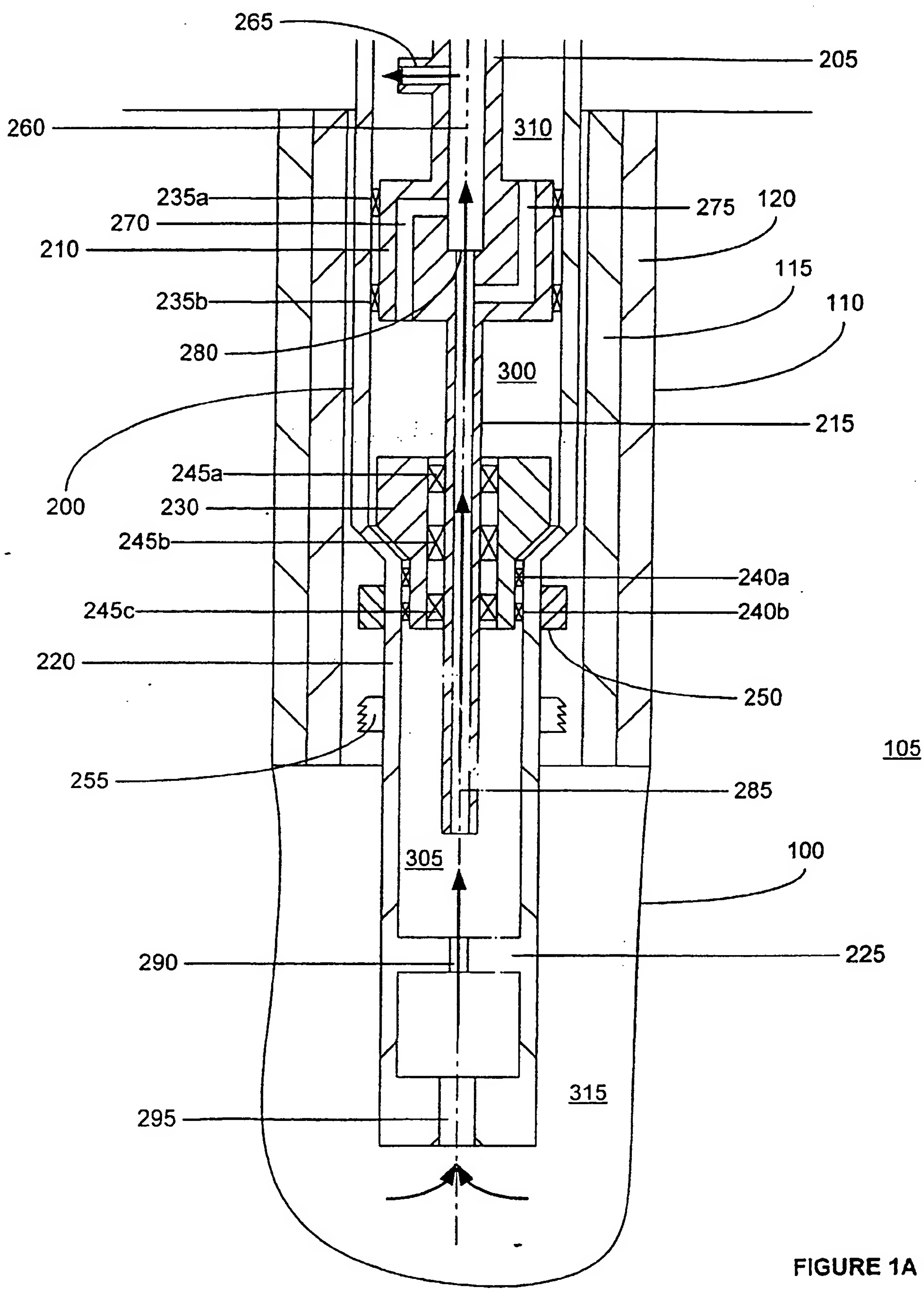
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245c
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250
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105
285
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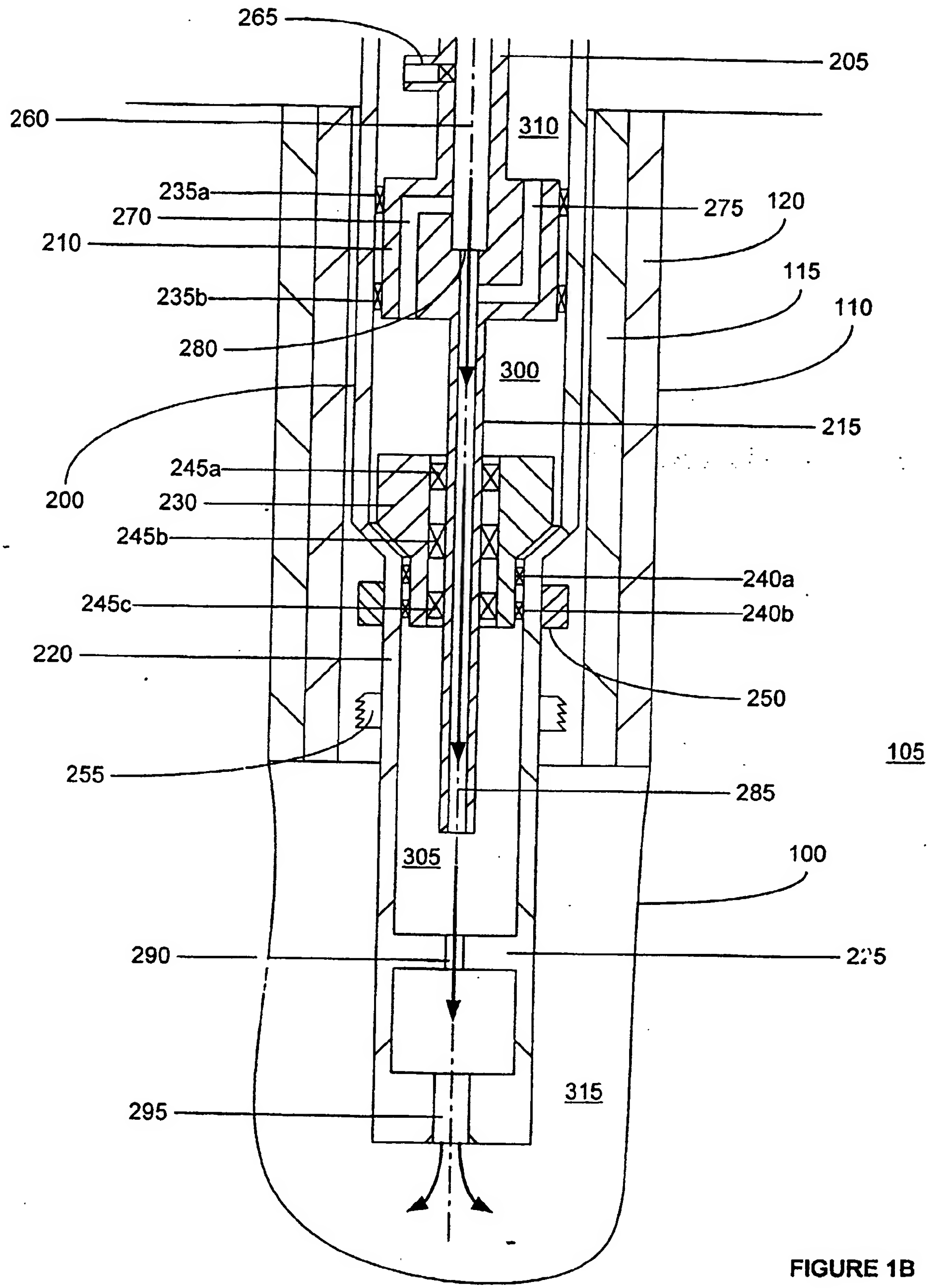
100
290
225
315
295

FIGURE 1A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240b
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100
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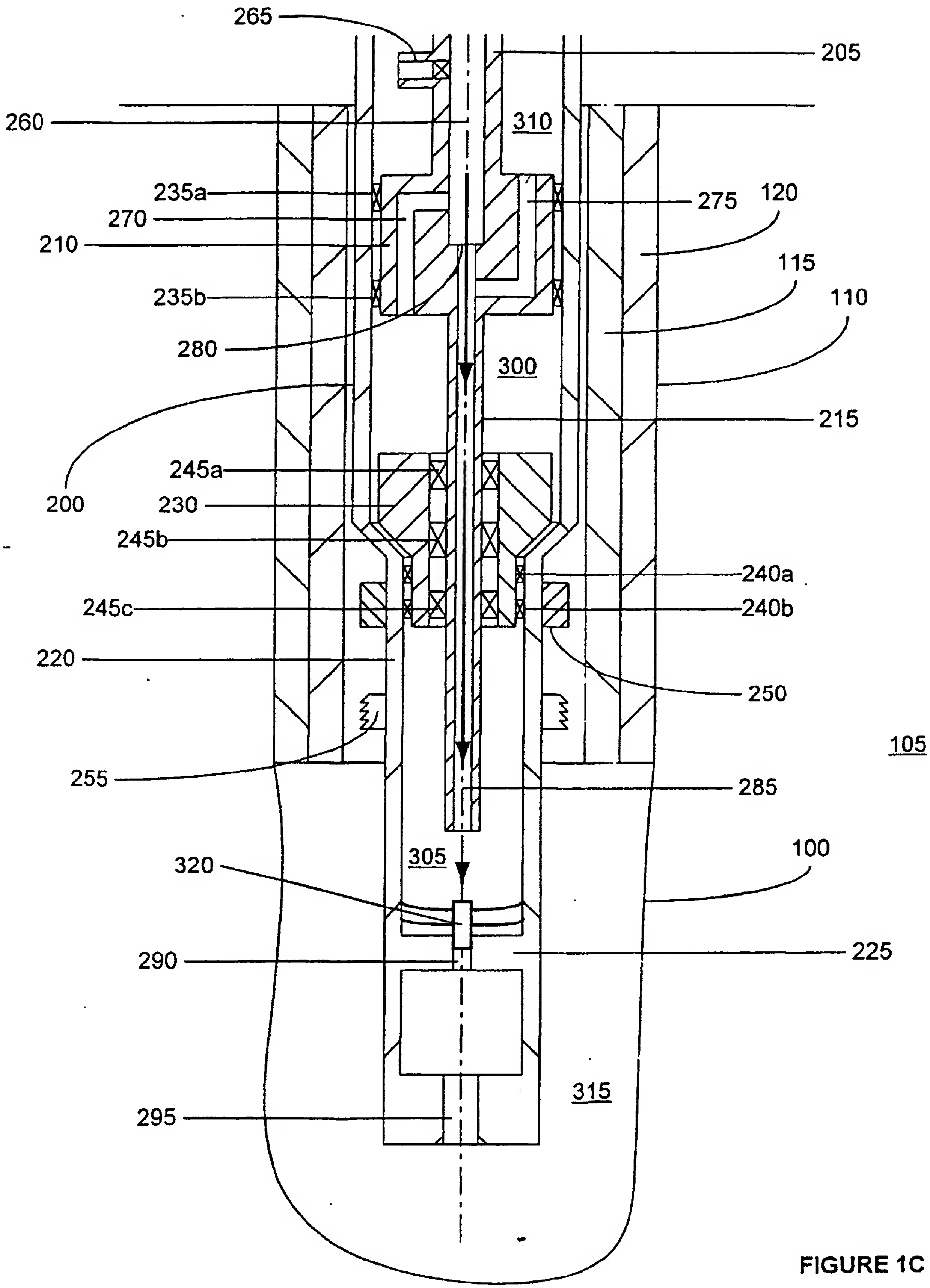
FIGURE 1B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285
305
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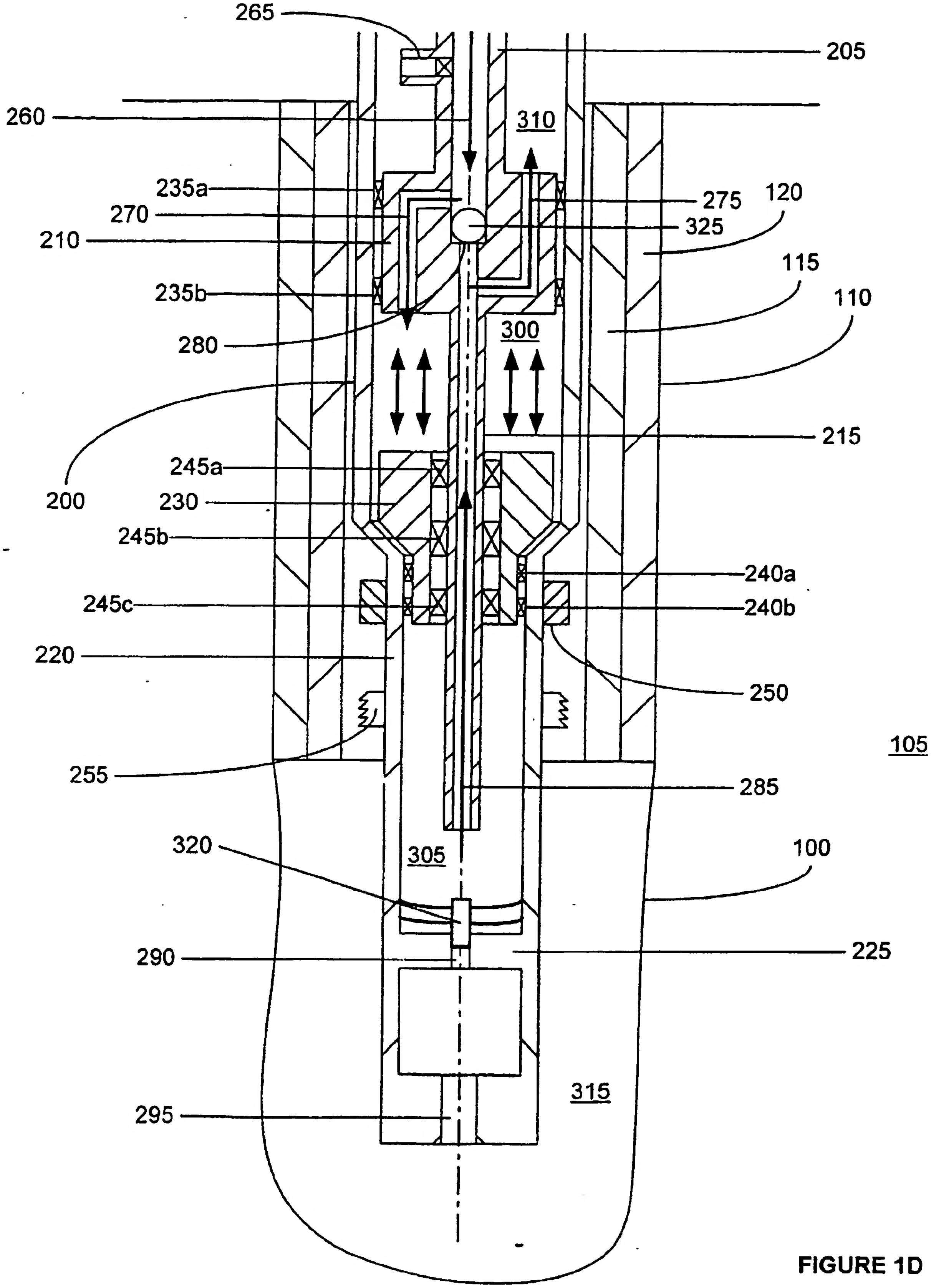
320
290
225
315
295

FIGURE 1C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315

FIGURE 1D

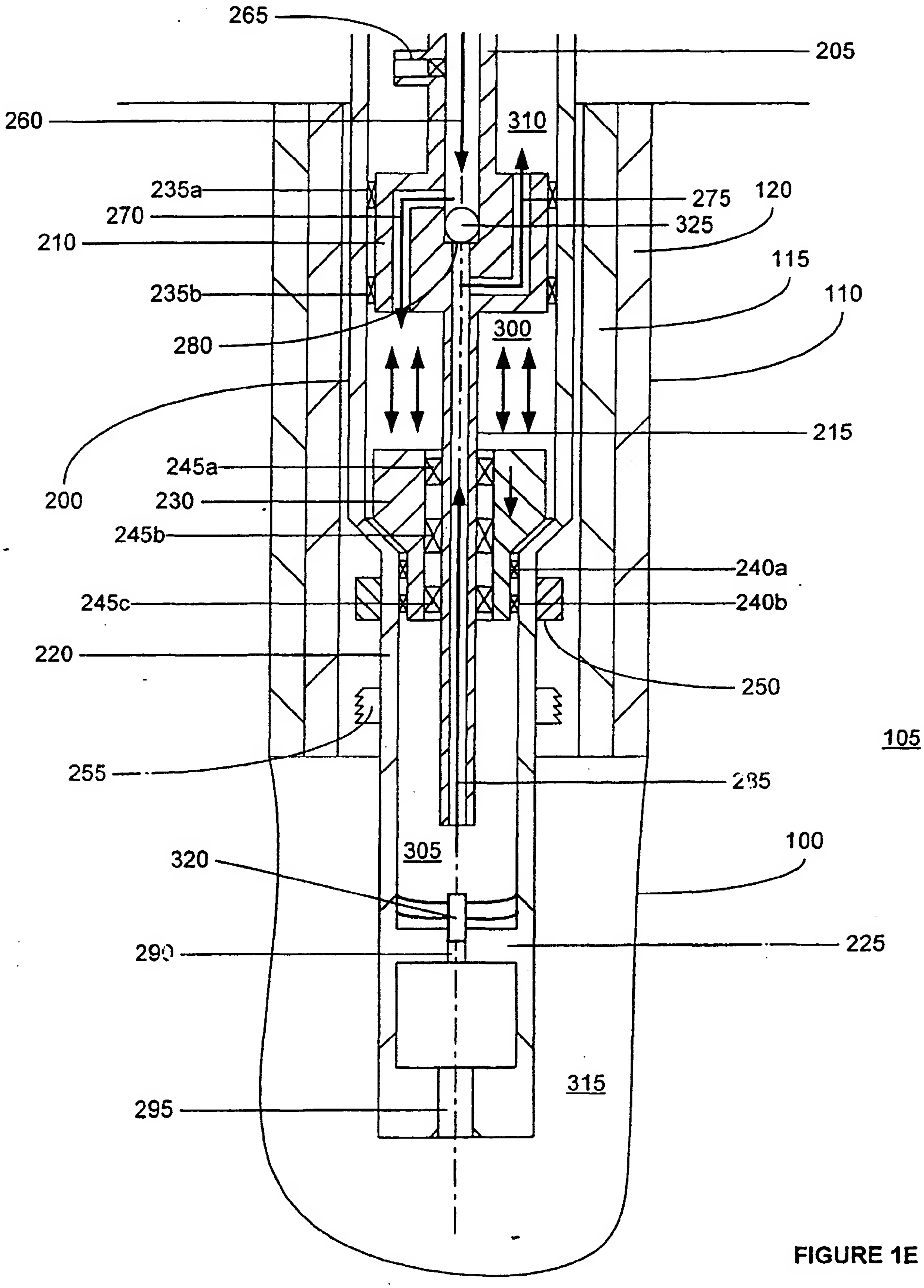
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FIGURE 1E

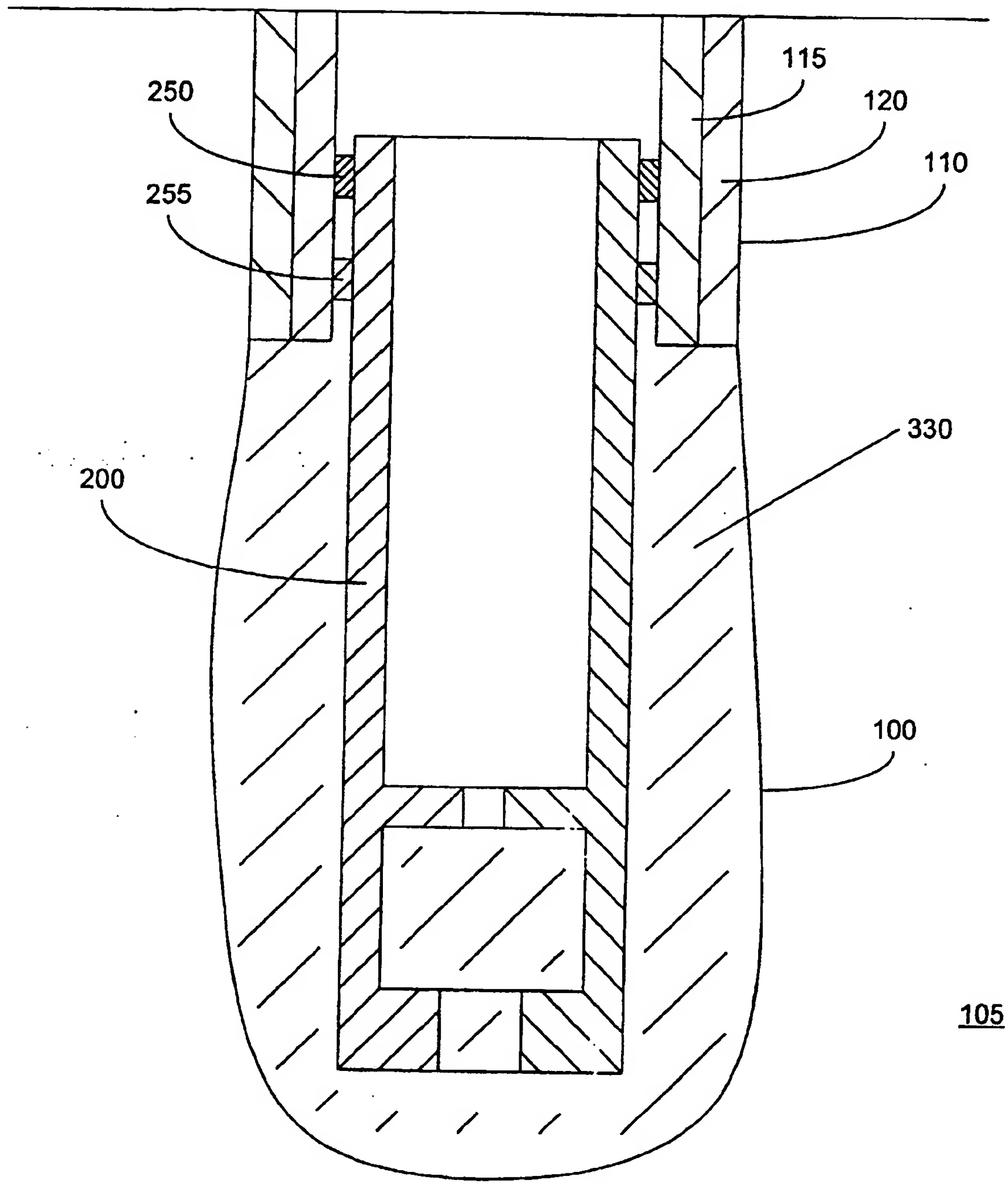
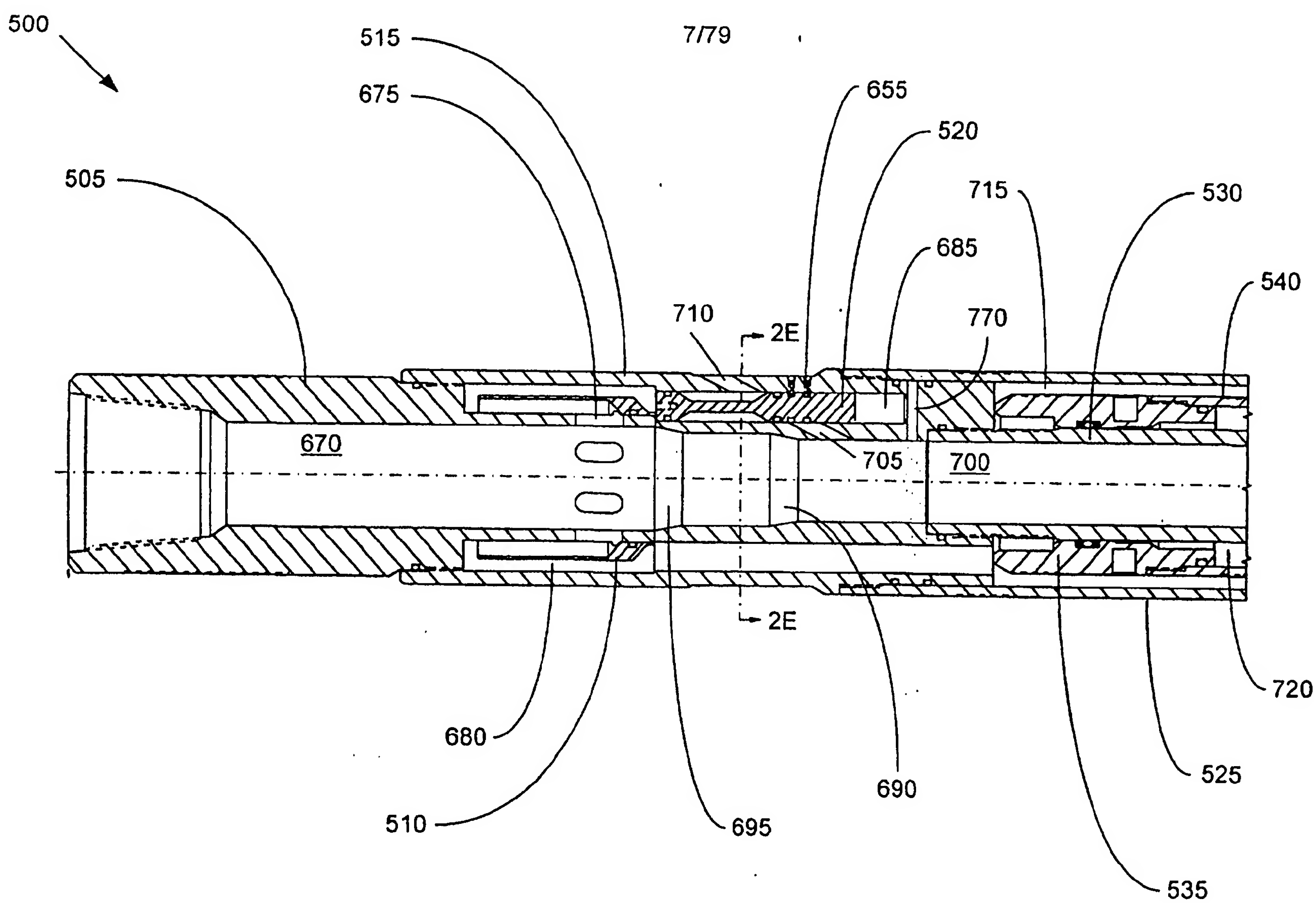


FIGURE 1F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2E
680
510
695
690
535
525
720

FIGURE 2A

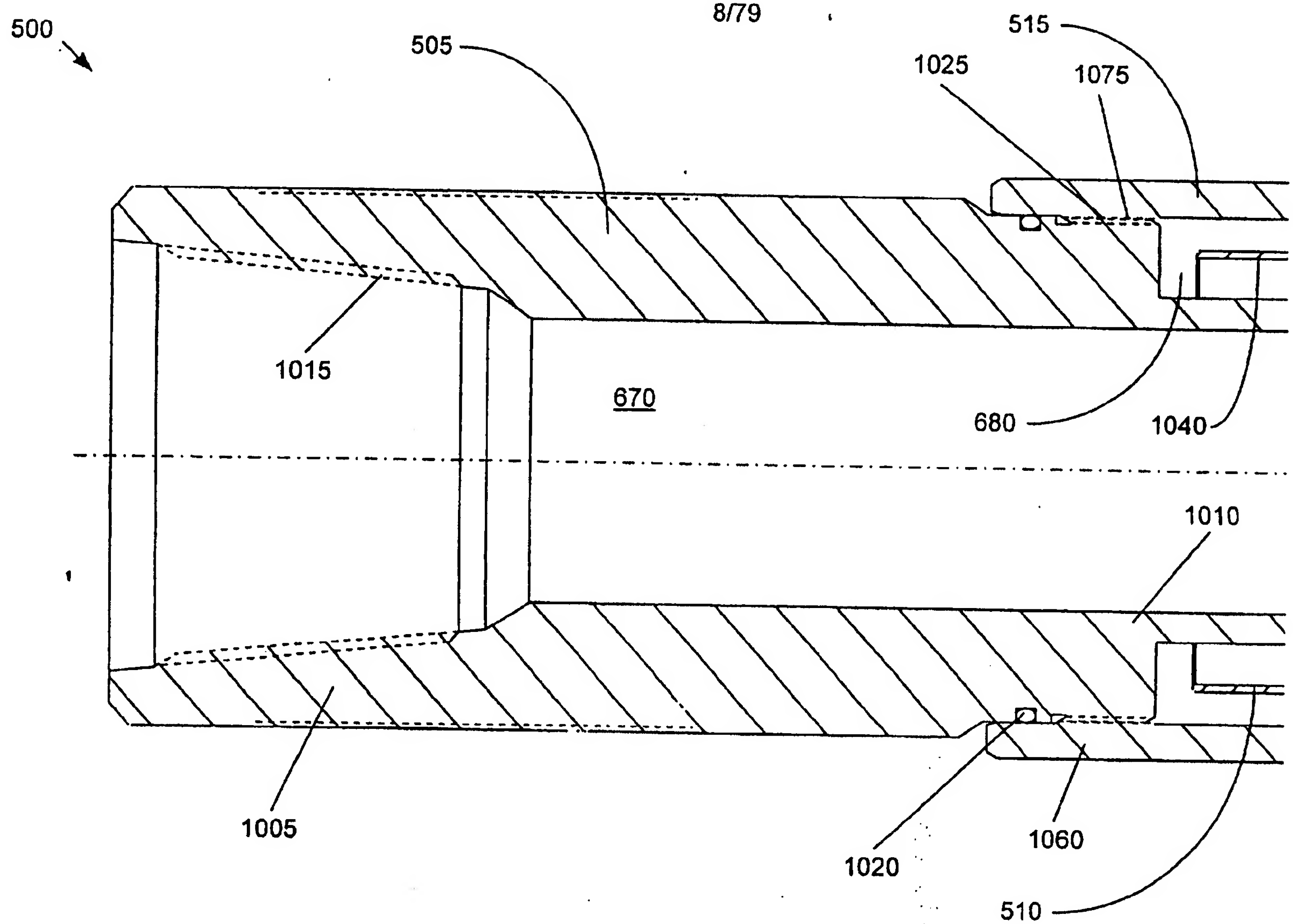
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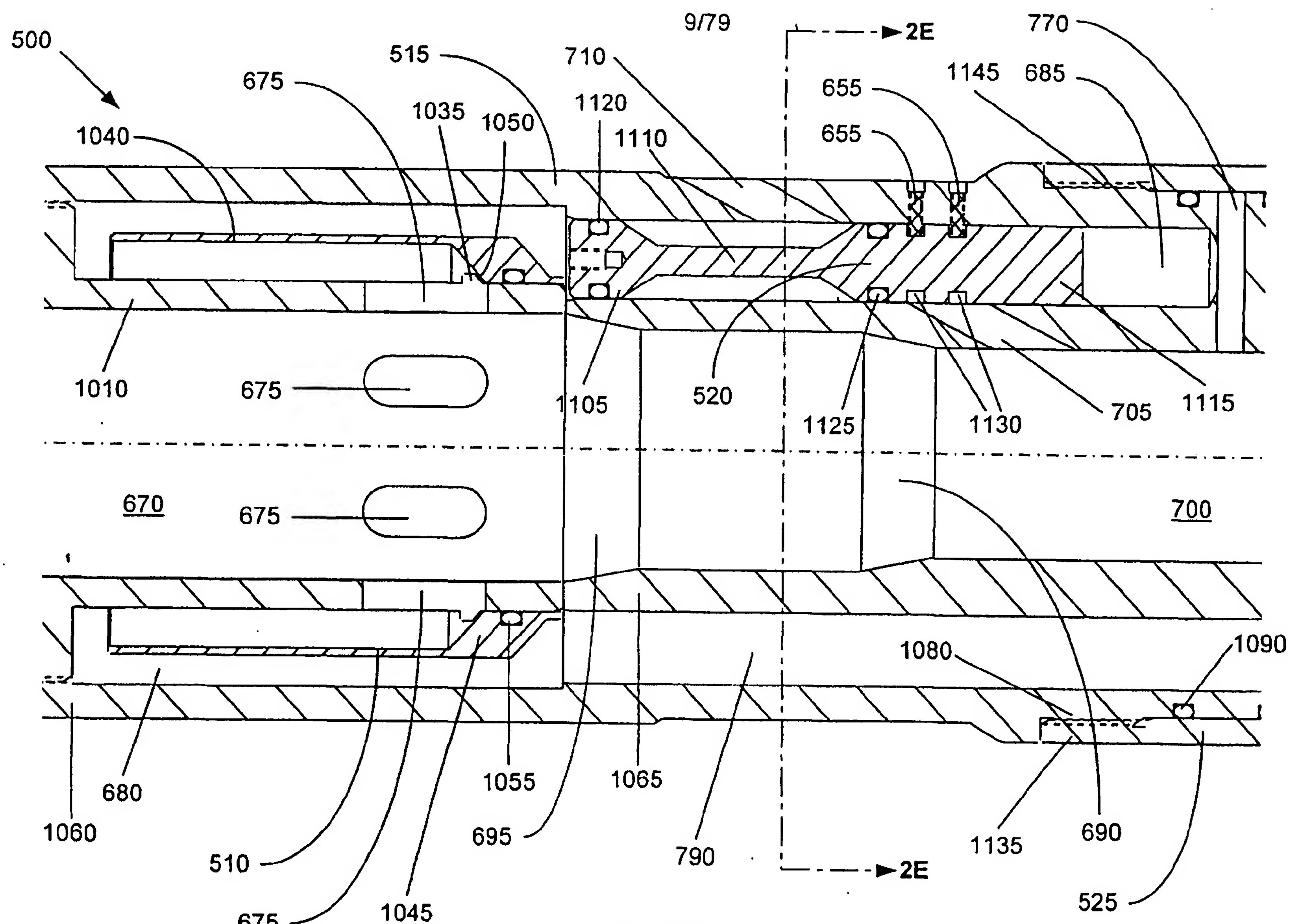
FIGURE 2B



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520
1125
1130
705
1115
670
675
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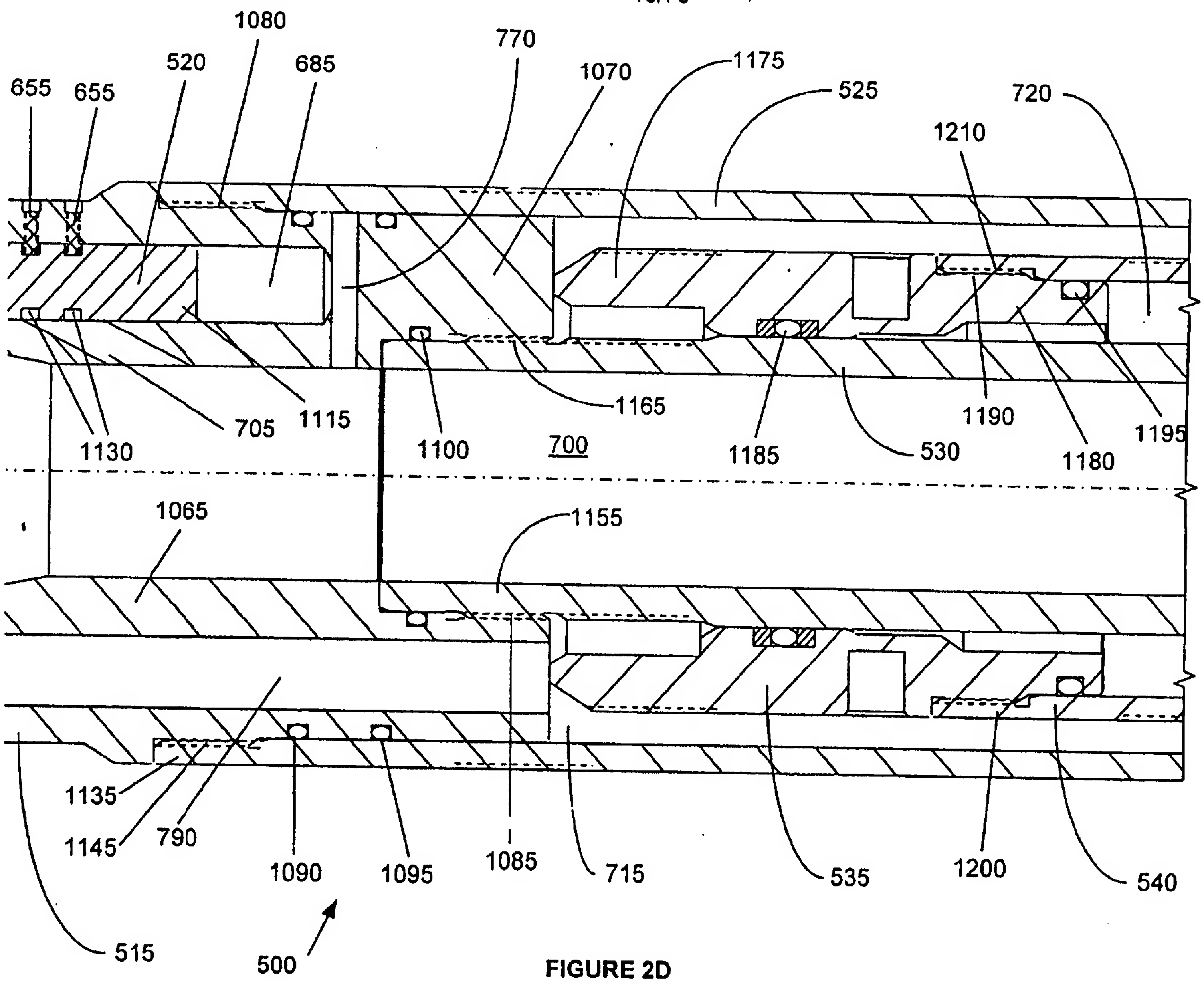
525
2E

FIGURE 2C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530
1190
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515
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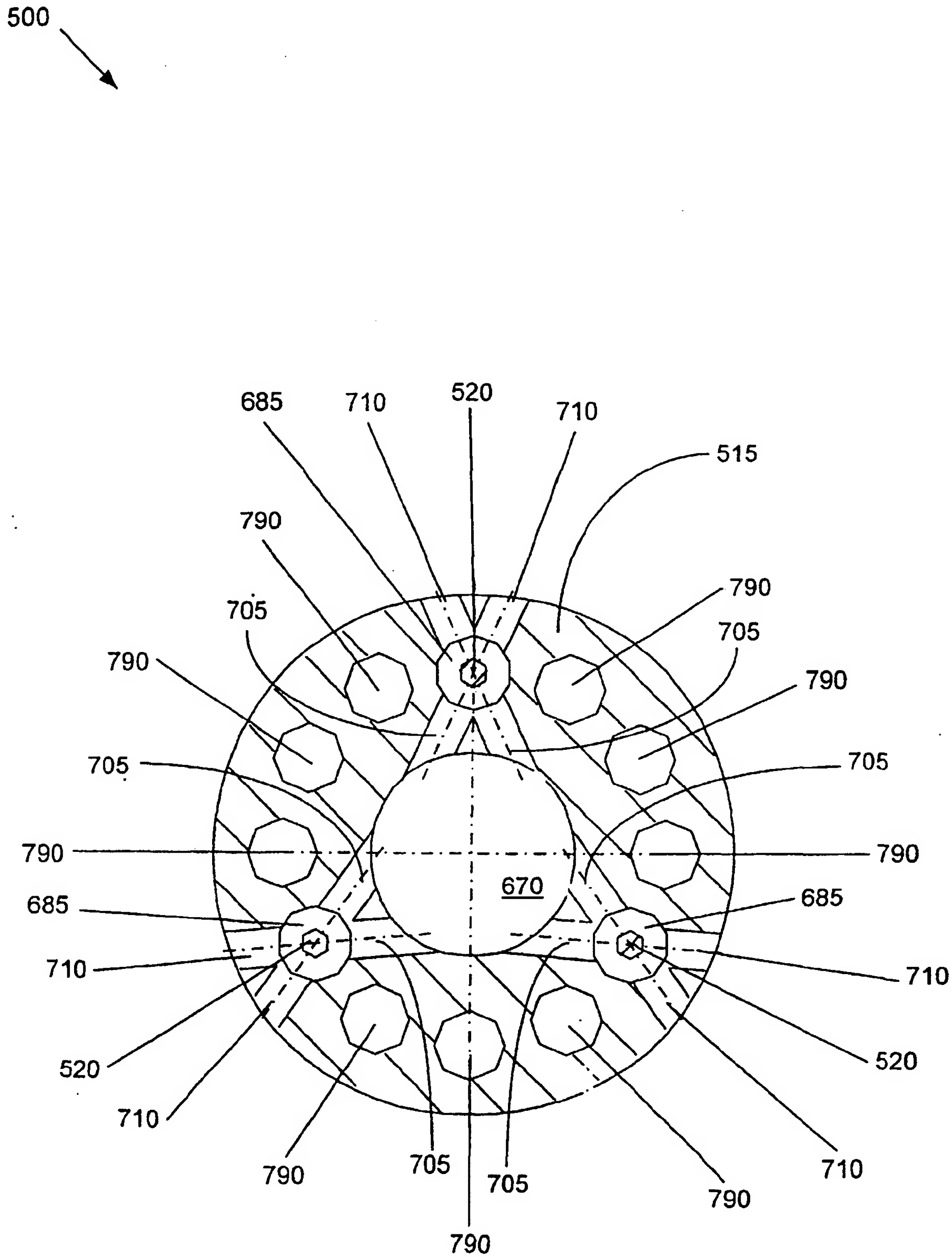
FIGURE 2D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790

FIGURE 2E

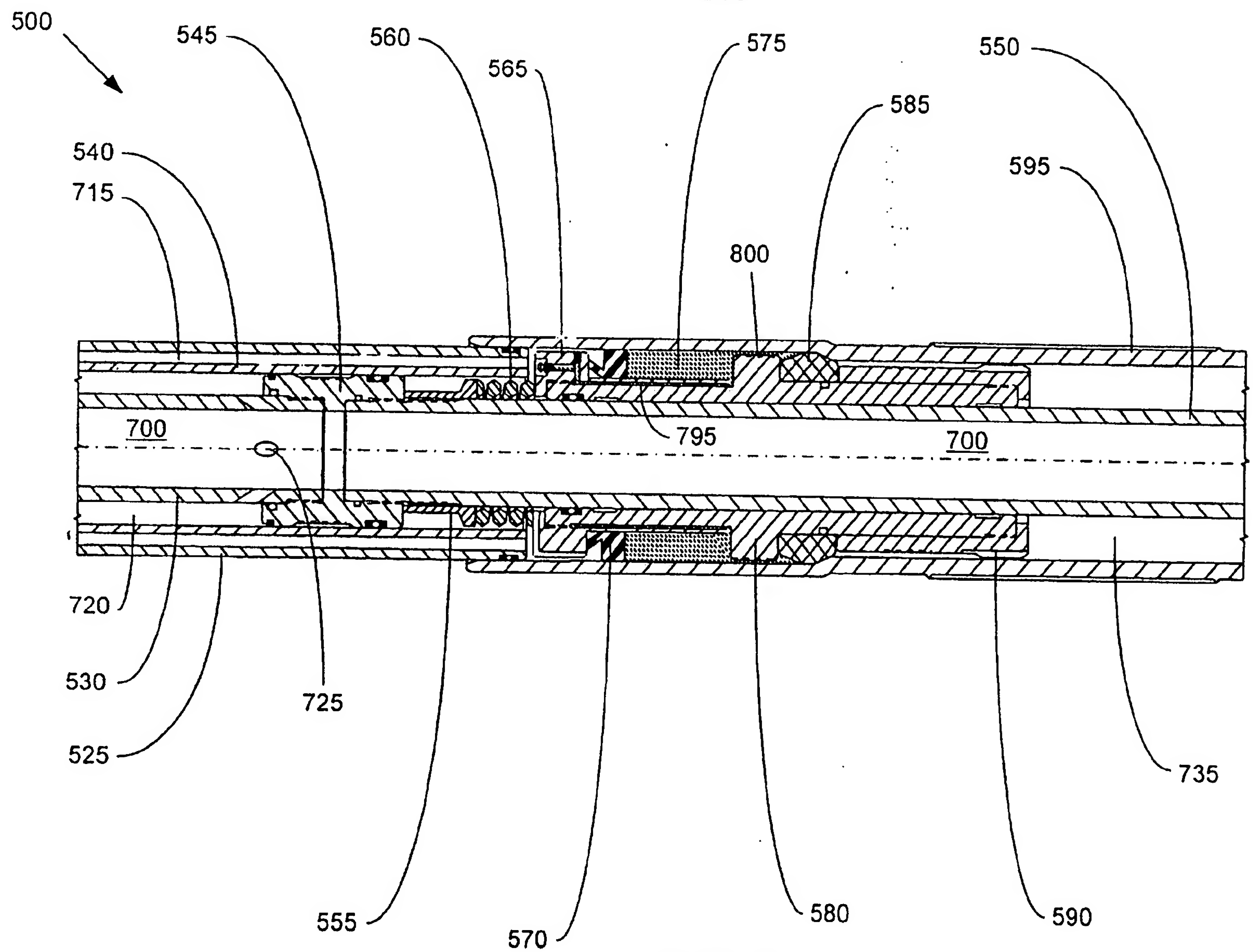
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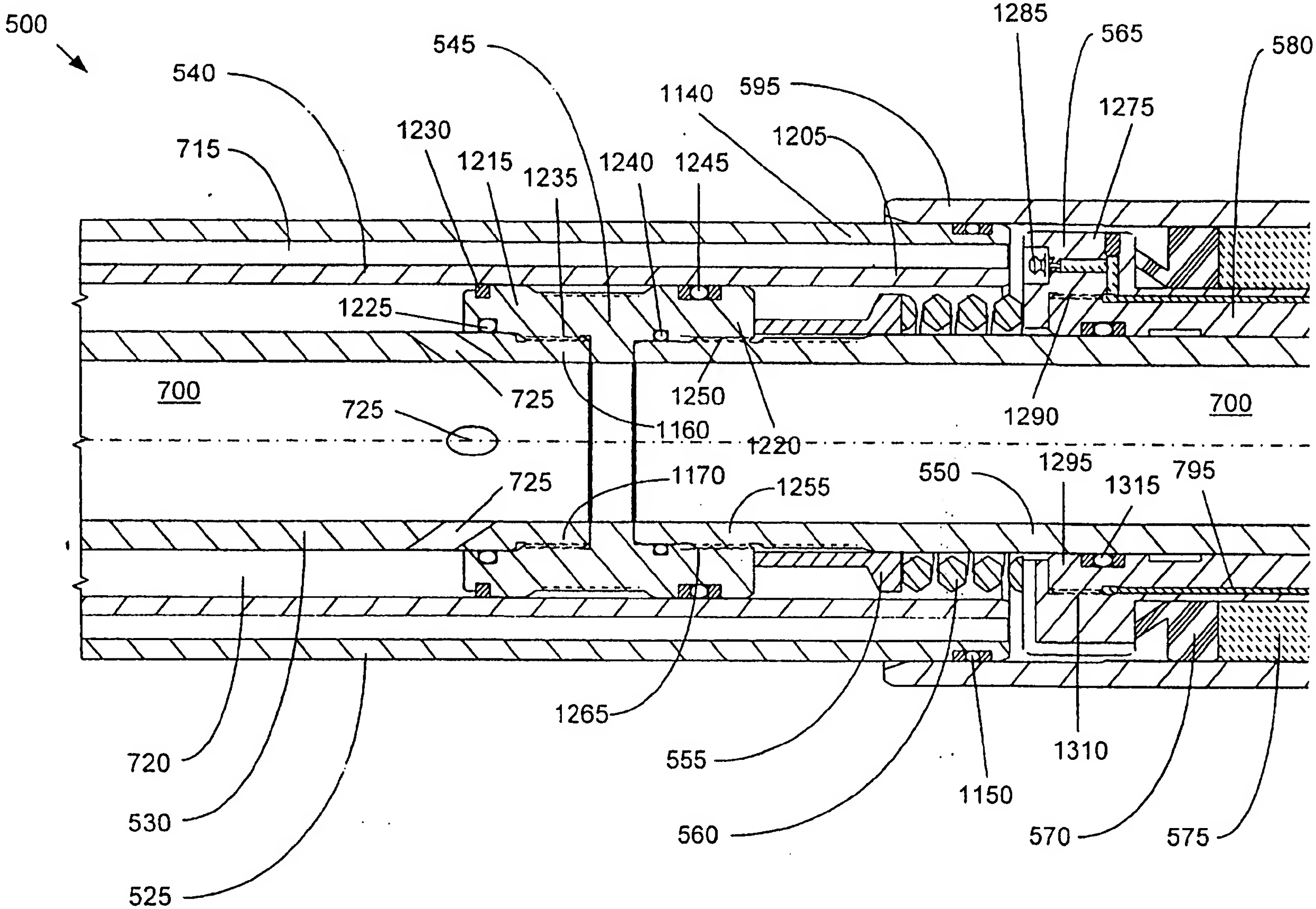
FIGURE 2F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1310
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525
560
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FIGURE 2G

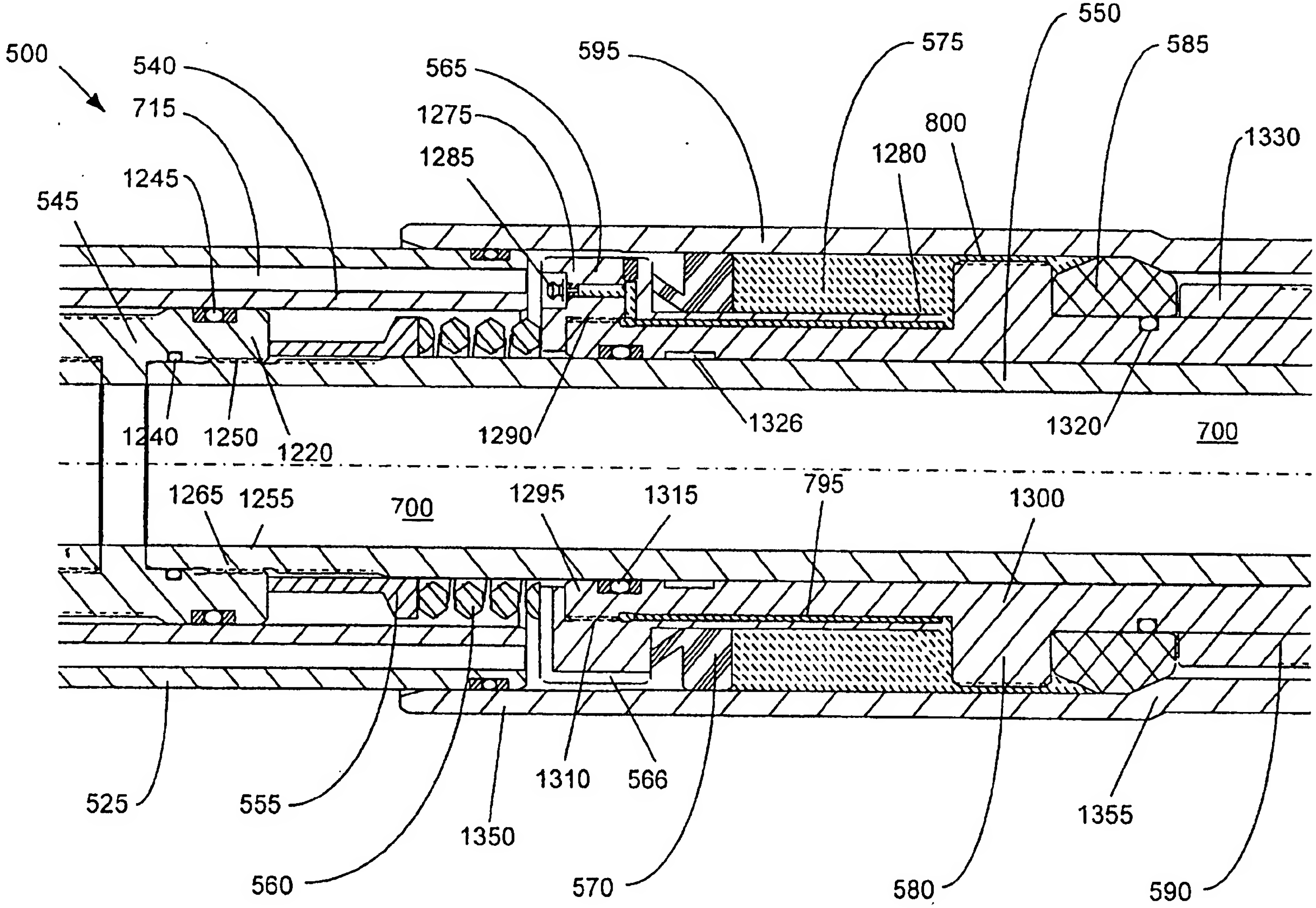
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FIGURE 2H

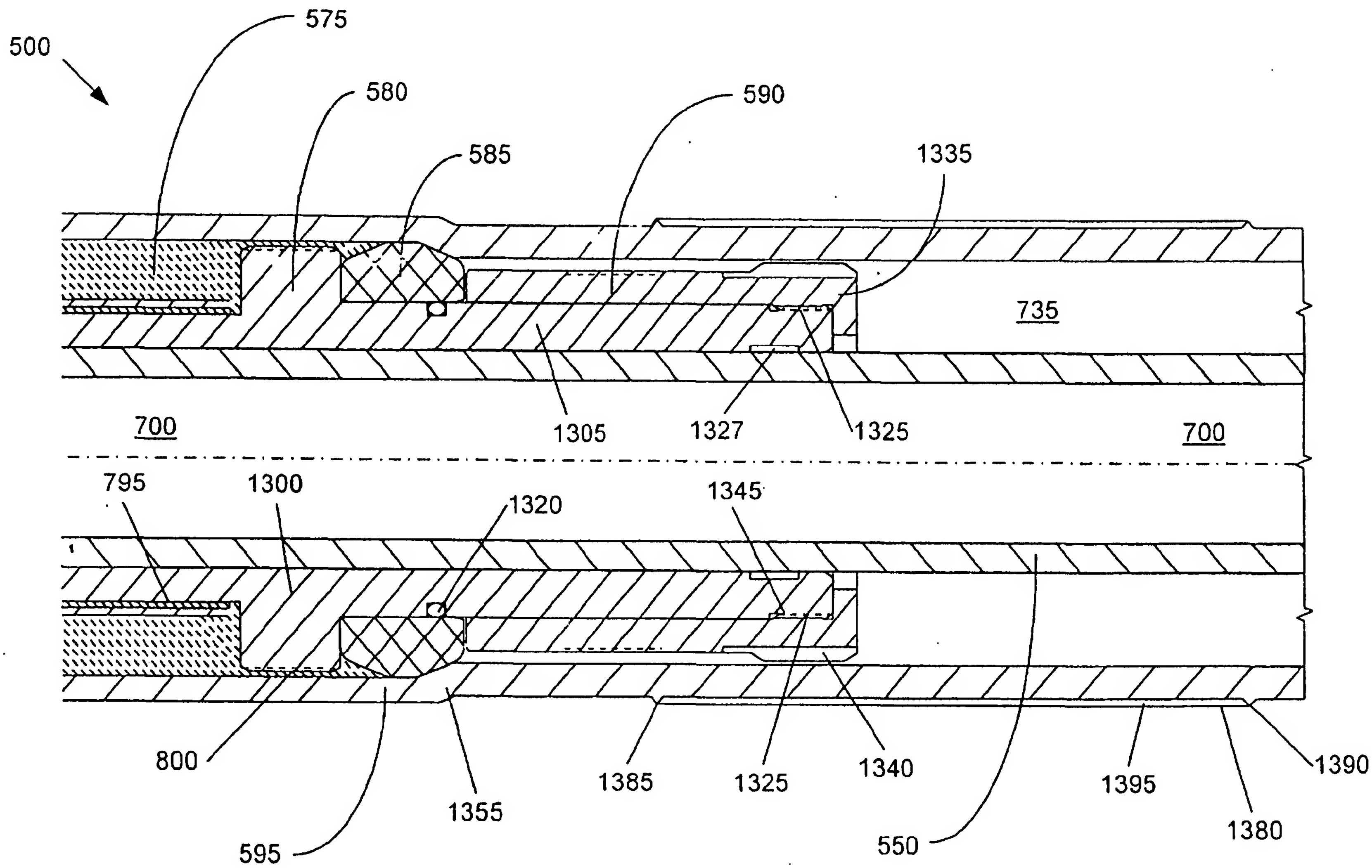
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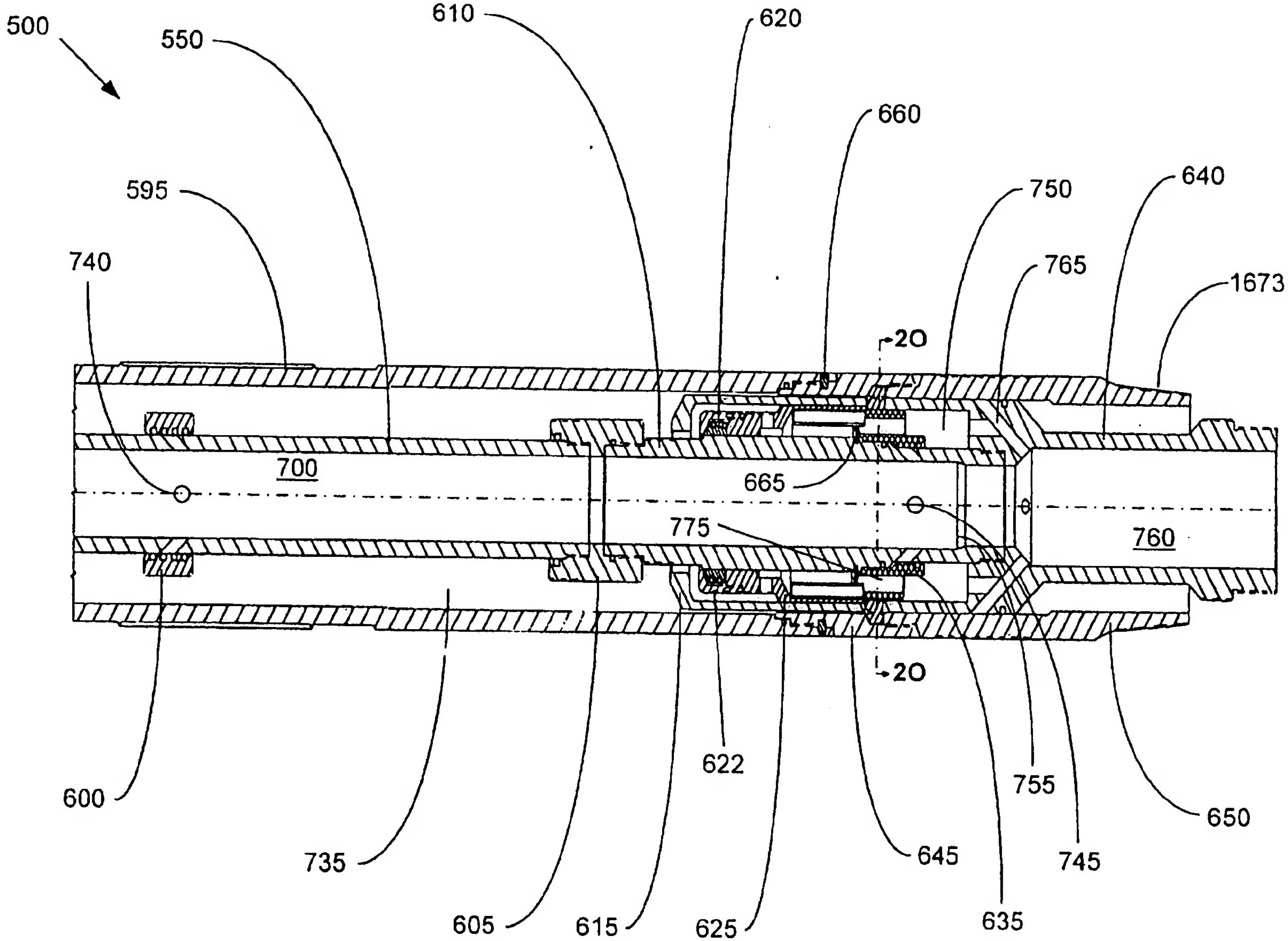
FIGURE 2I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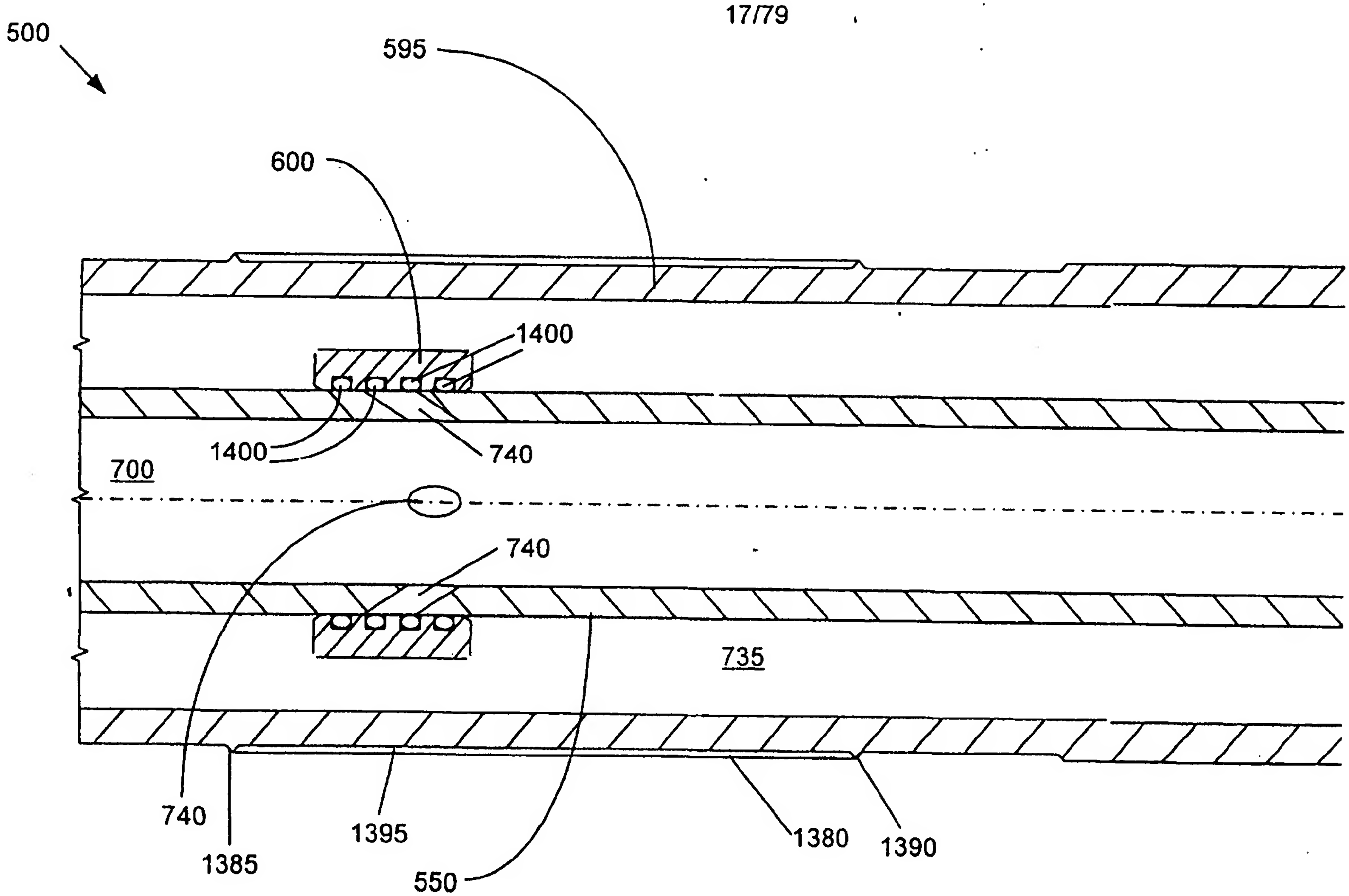
605
615
625
635

FIGURE 2J



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1400
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550
1380
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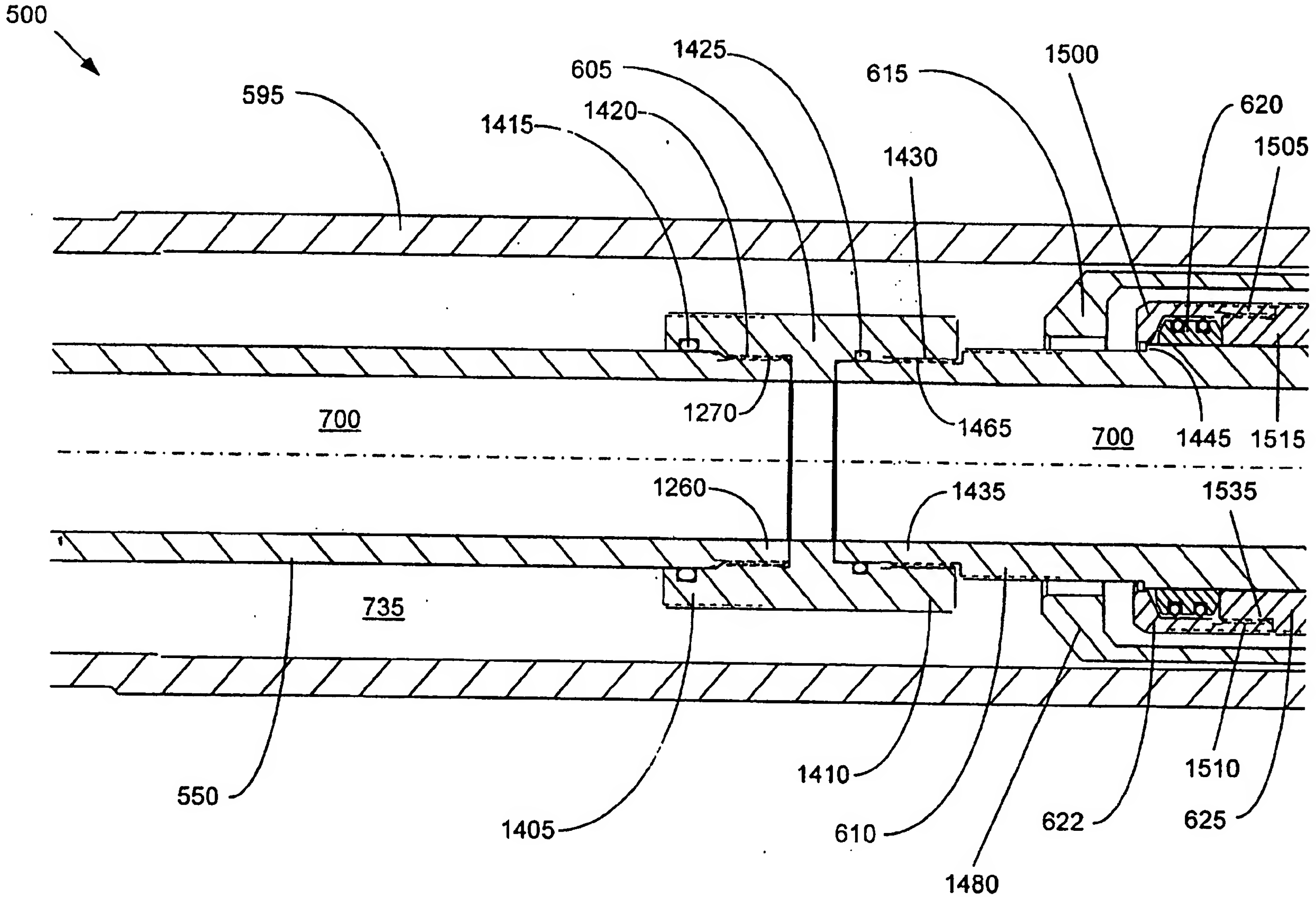
FIGURE 2K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735
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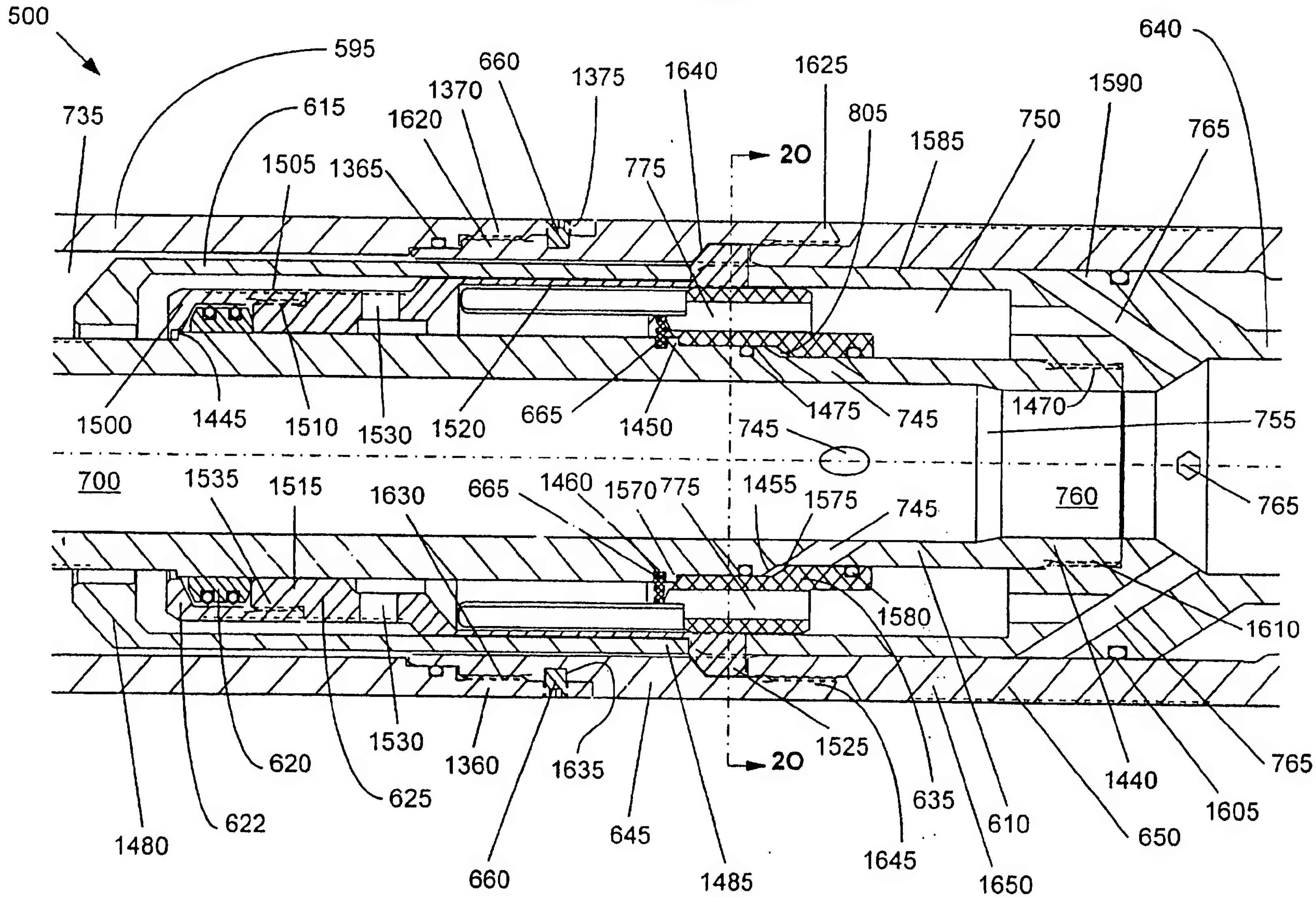
610
1480
622
1510
625

FIGURE 2L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620
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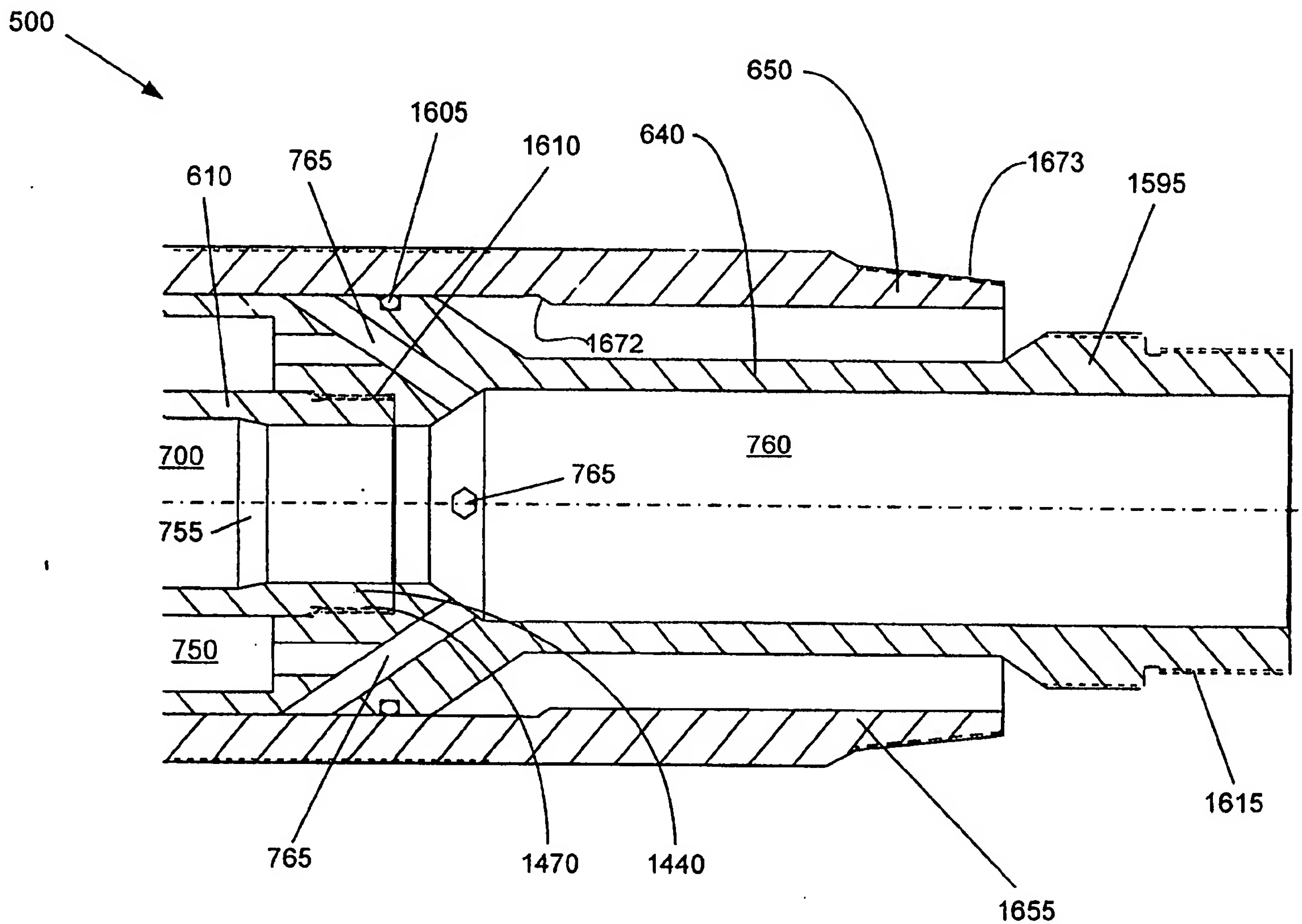
FIGURE 2M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1615

FIGURE 2N

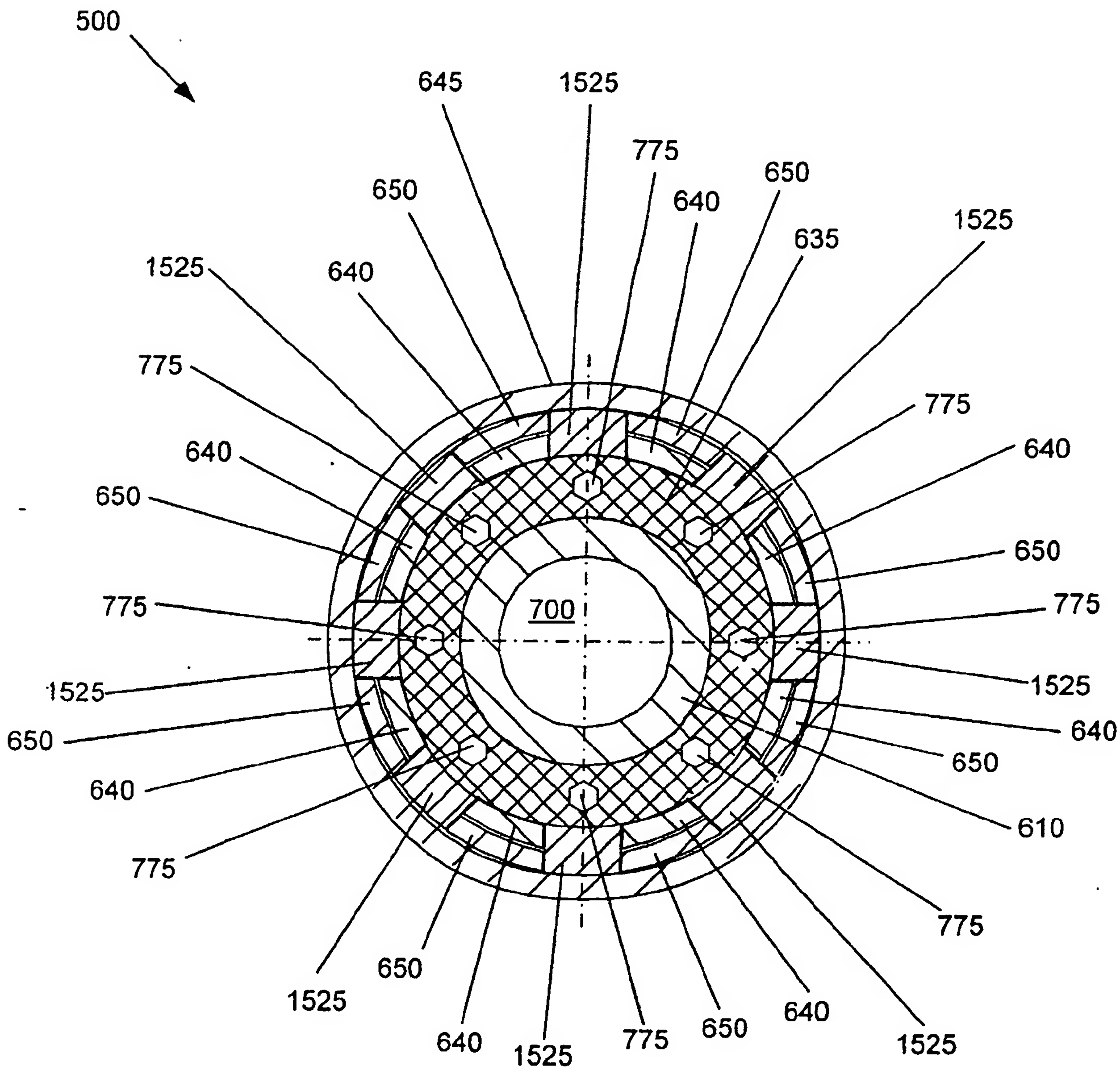
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FIGURE 2O

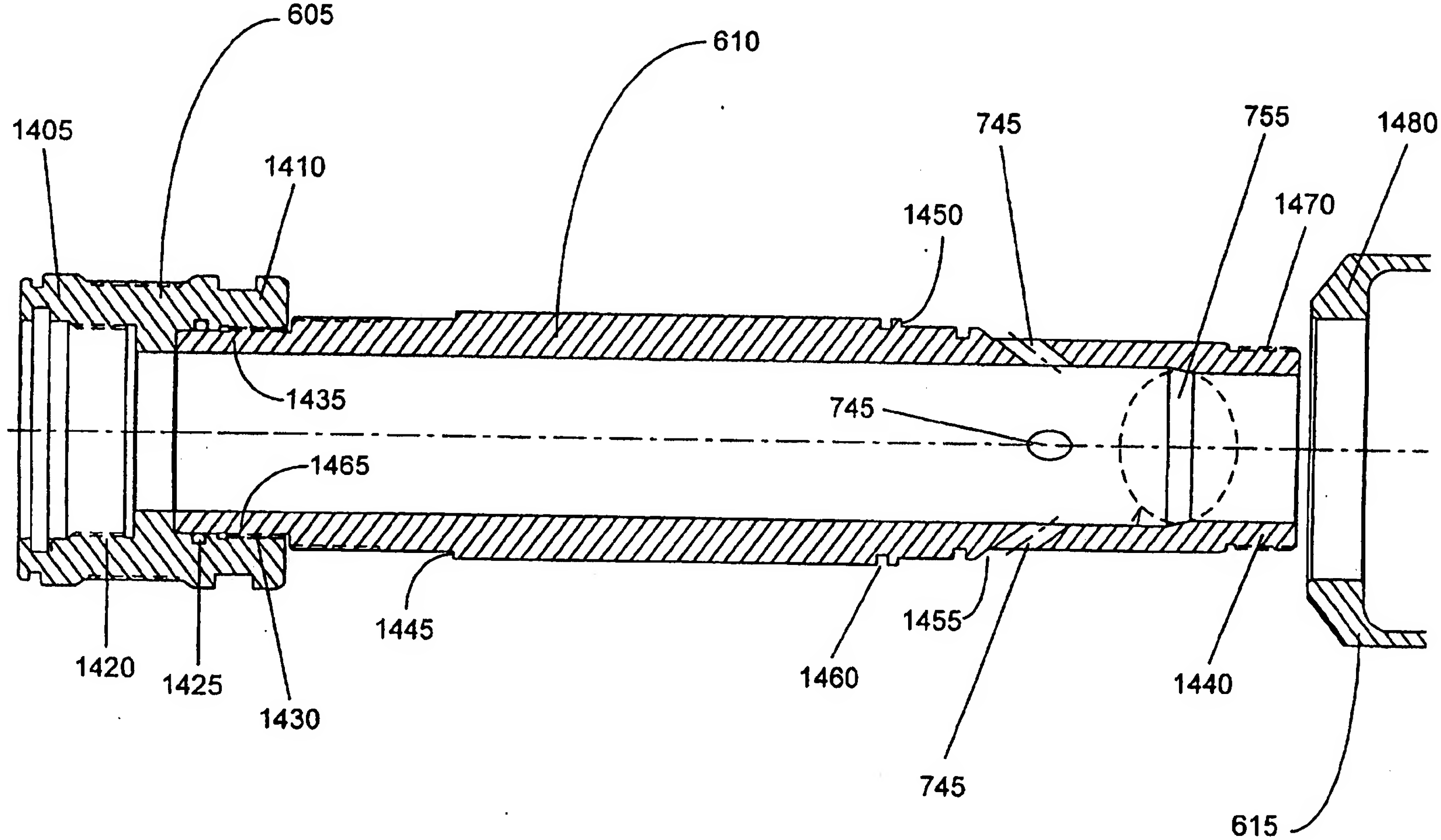
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FIGURE 3A

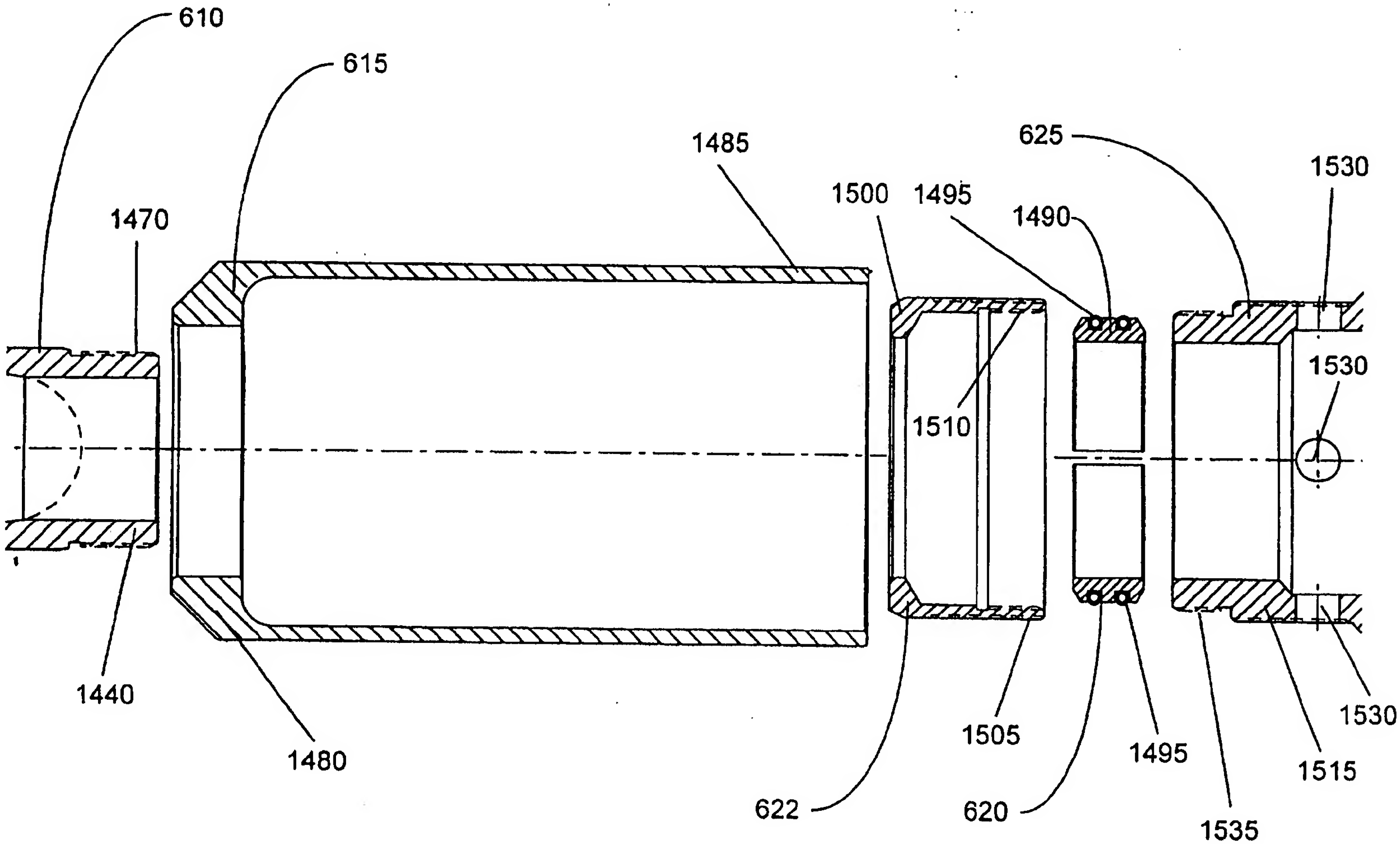
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FIGURE 3B

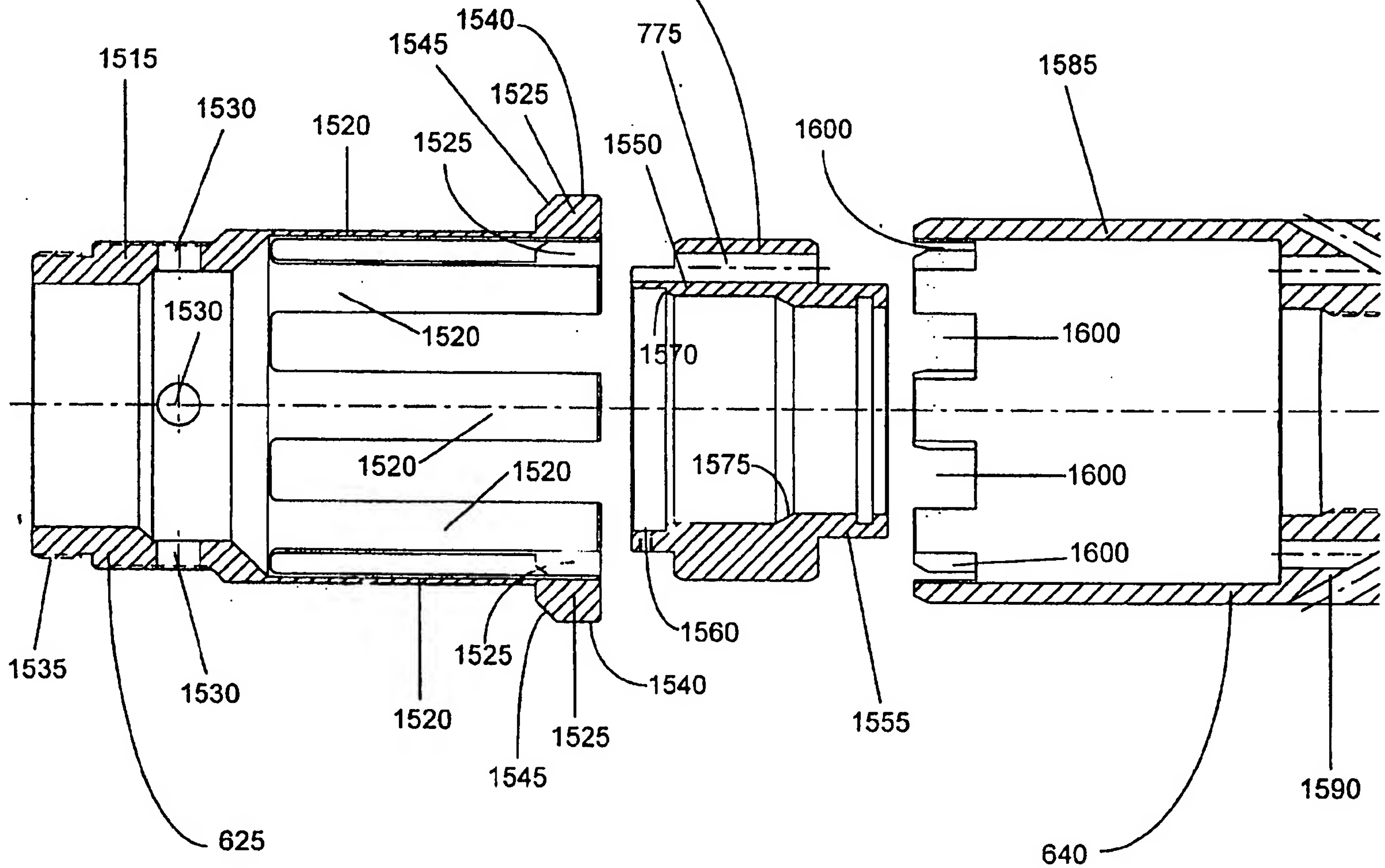
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FIGURE 3C

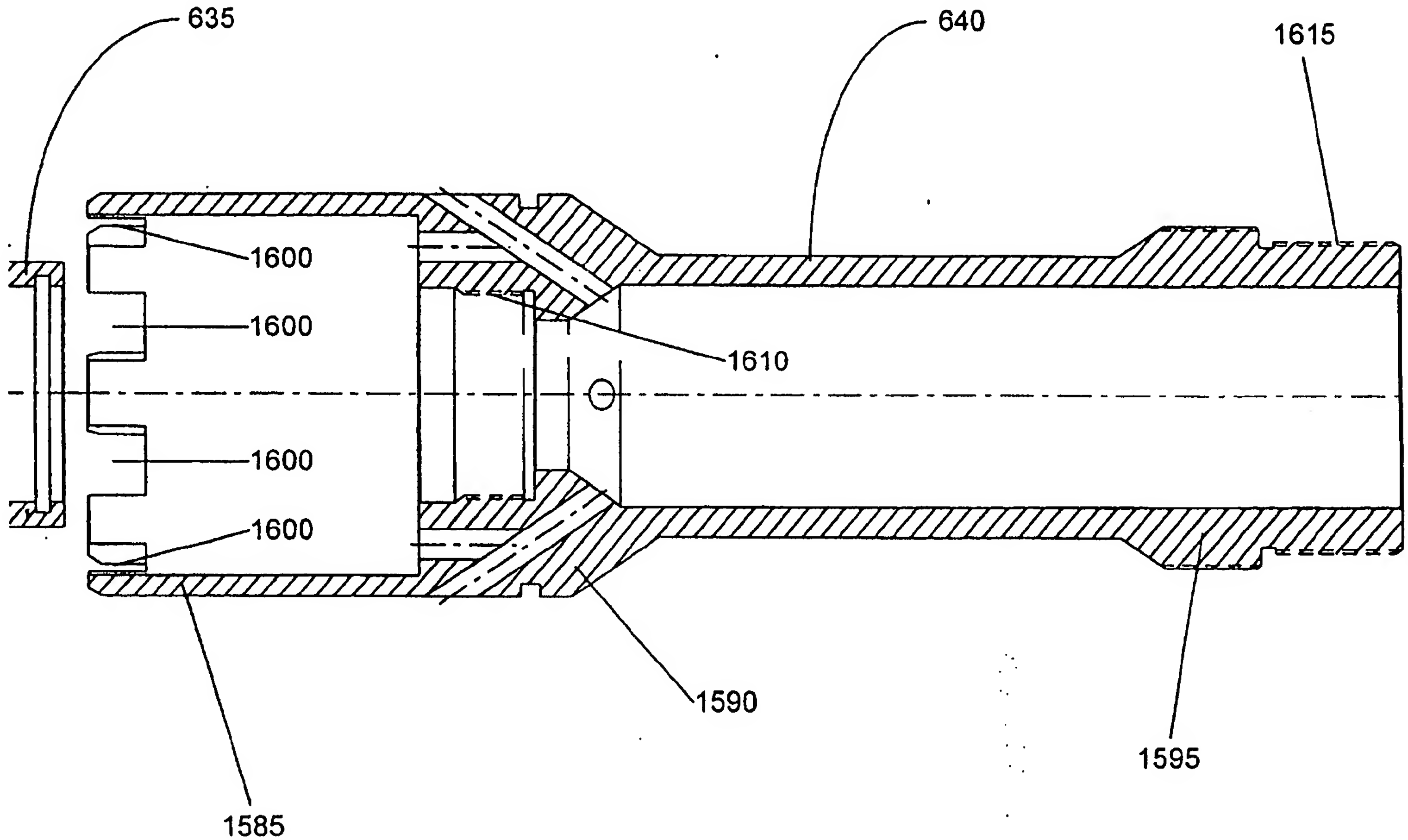

FIGURE 3D

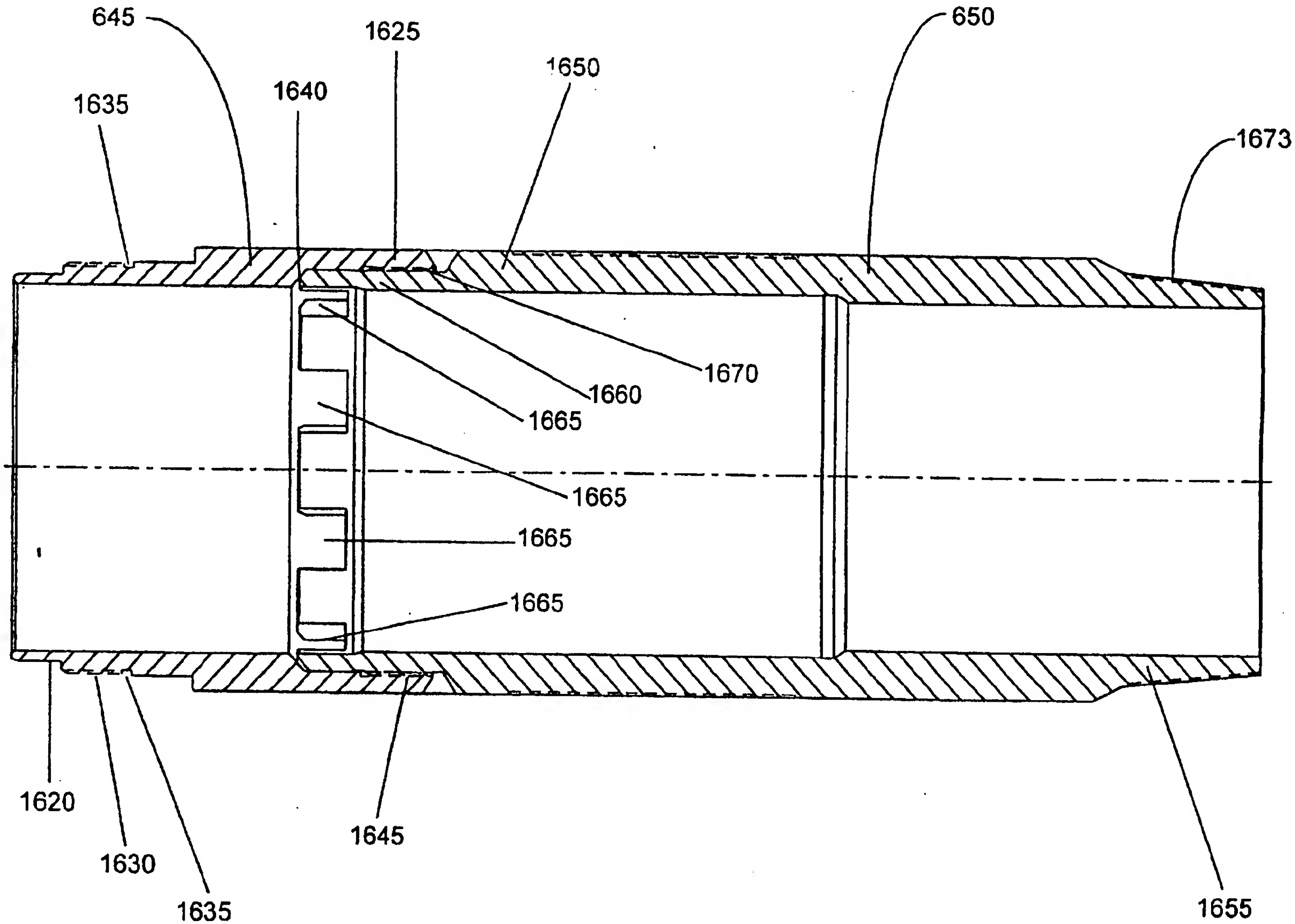
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FIGURE 3E

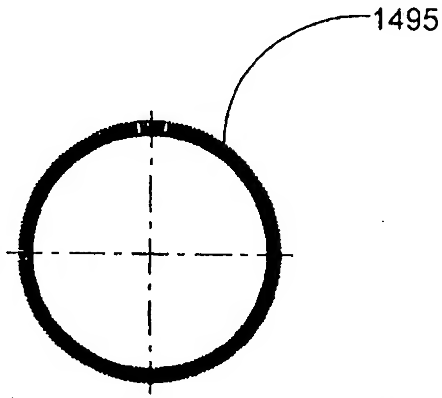

FIGURE 3F

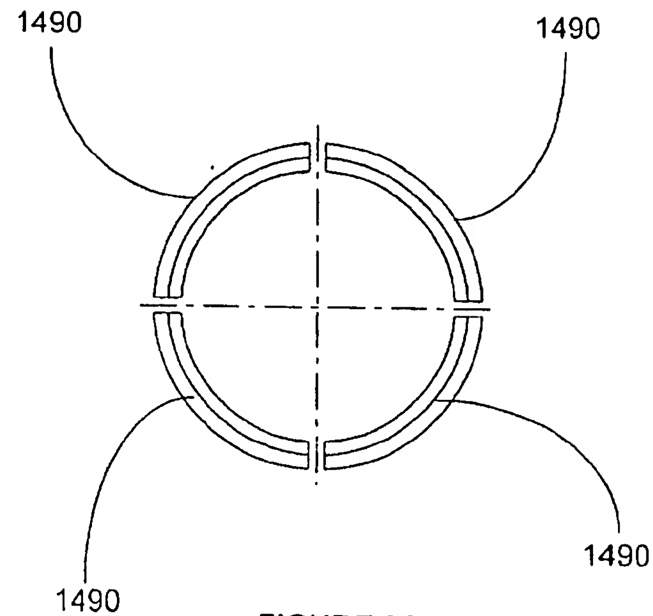

FIGURE 3G

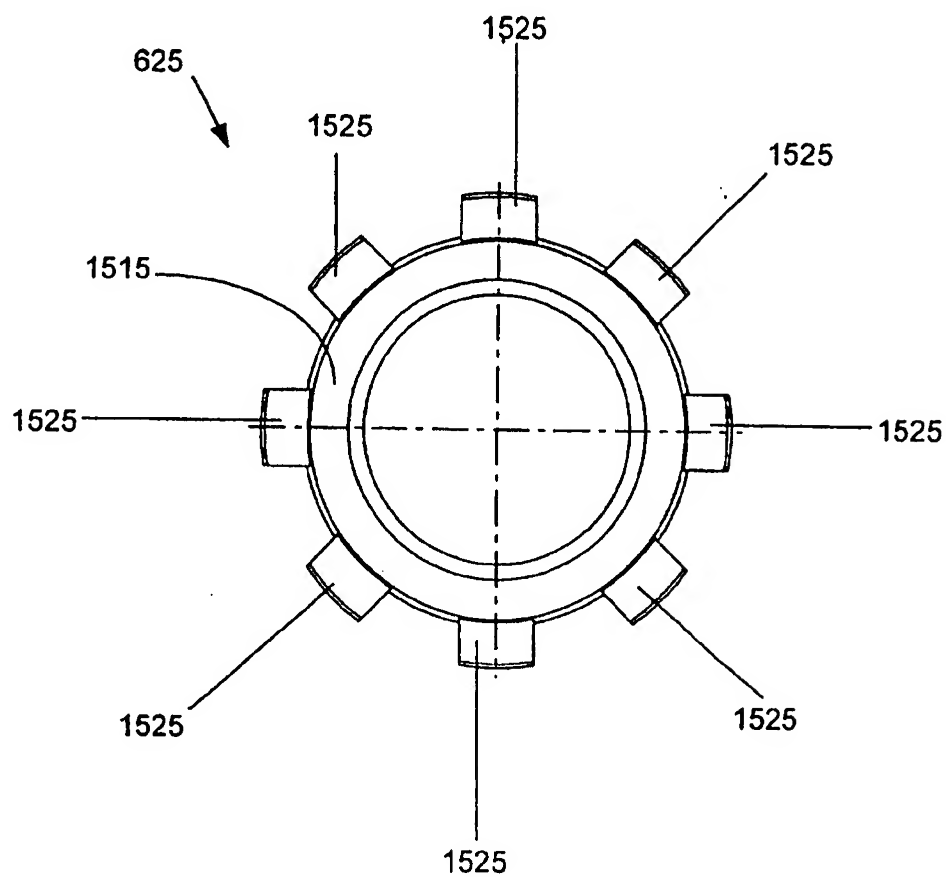

FIGURE 3H

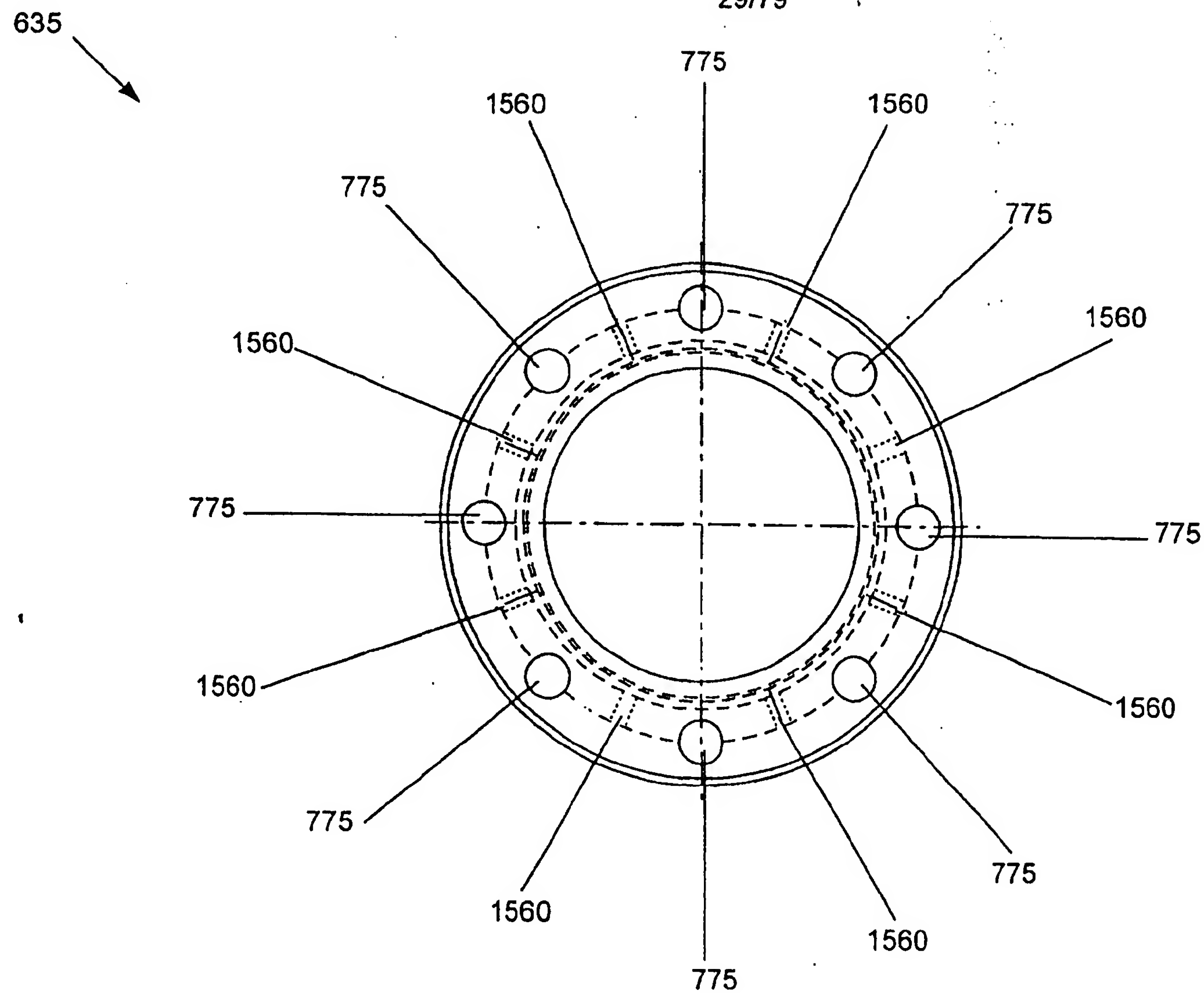
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FIGURE 3I

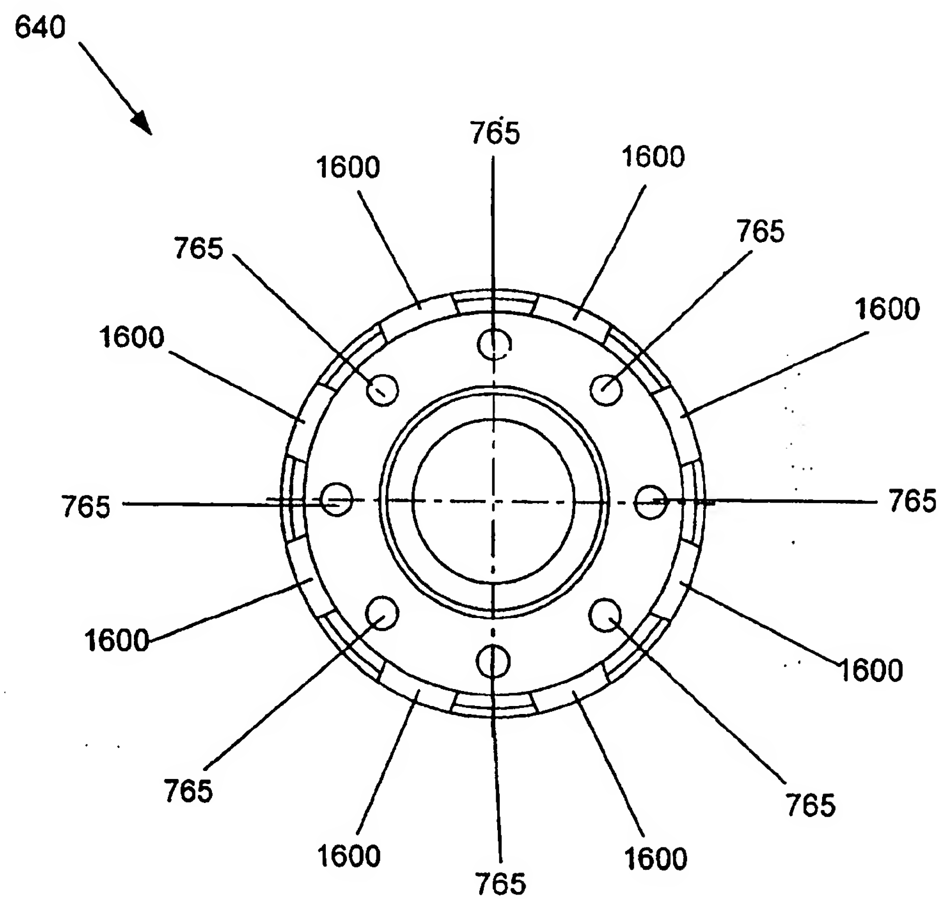
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FIGURE 3J

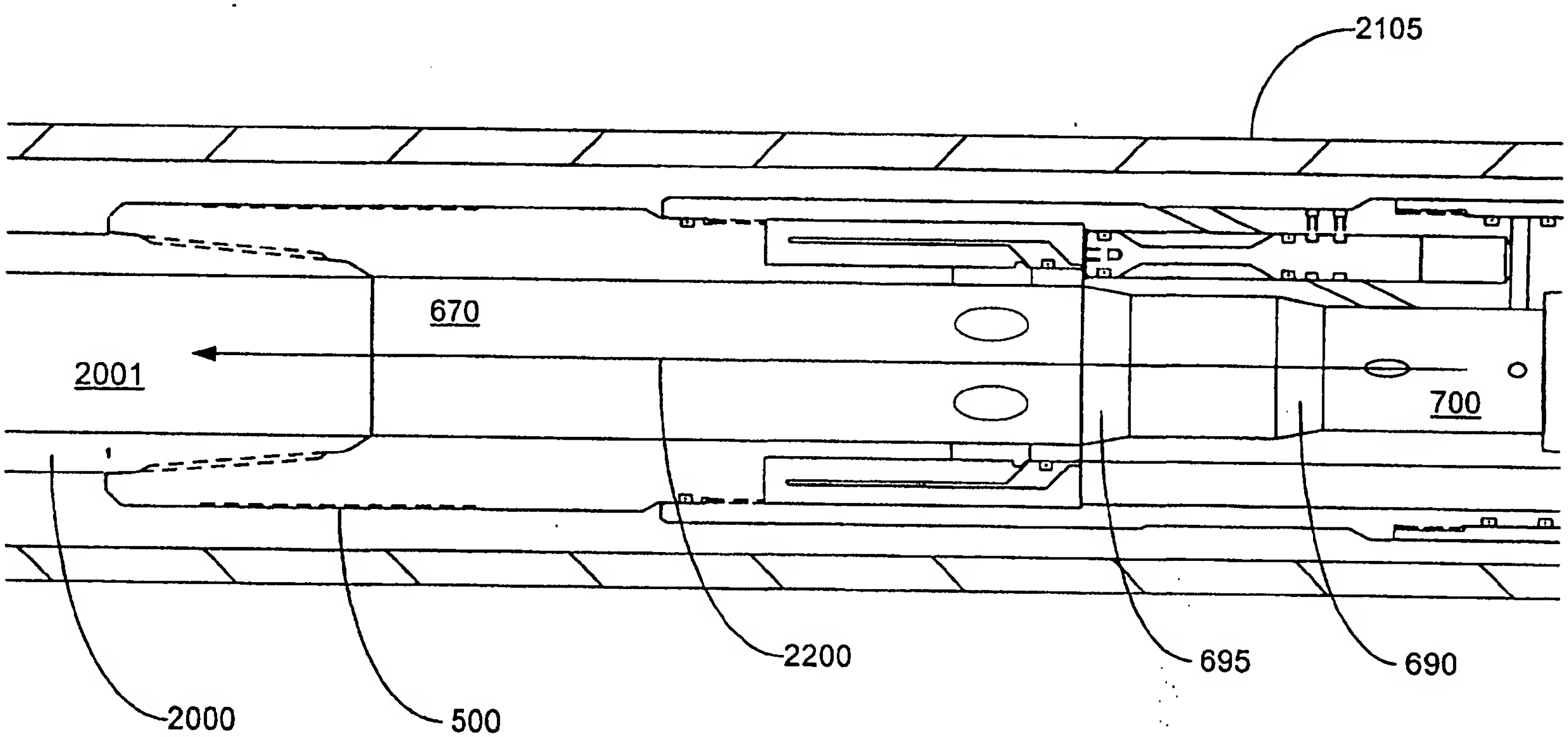

FIGURE 4A

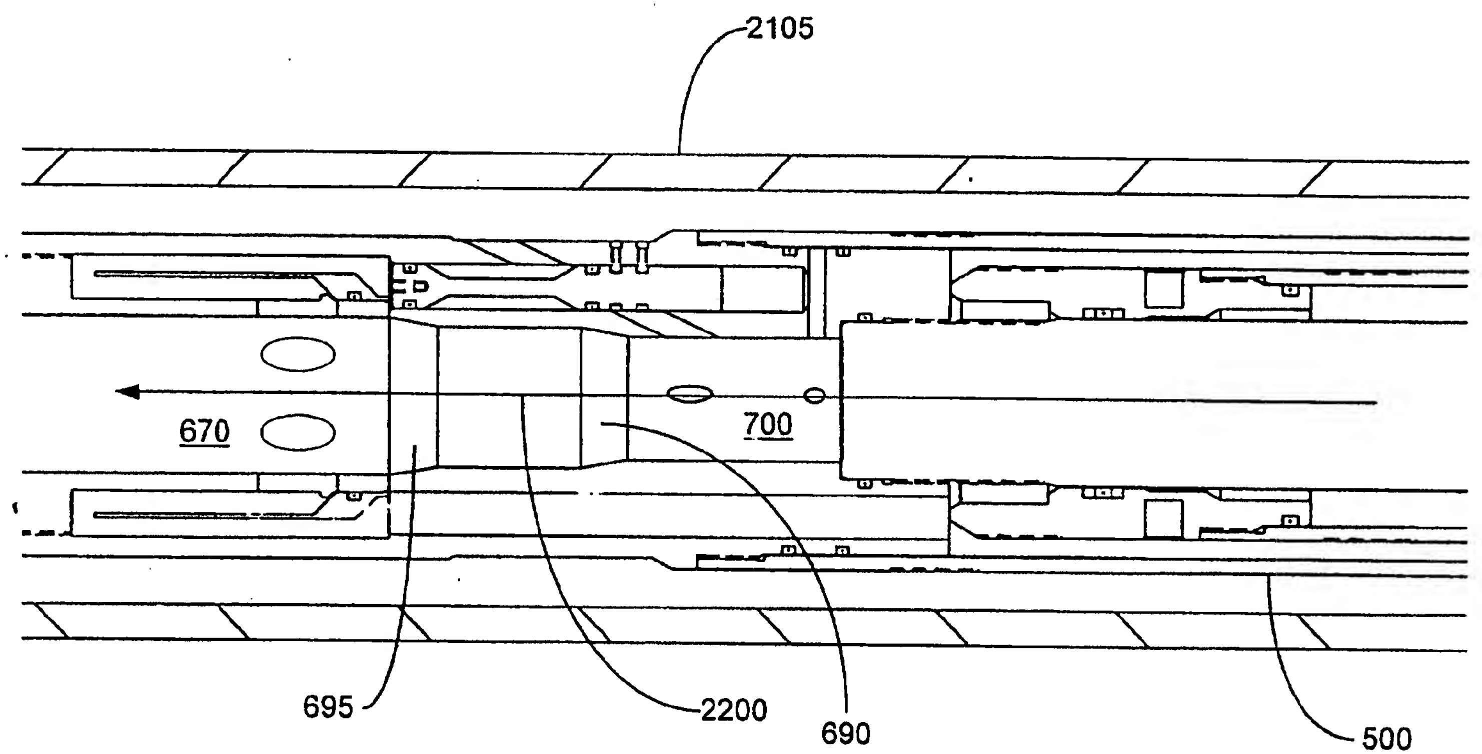

FIGURE 4B

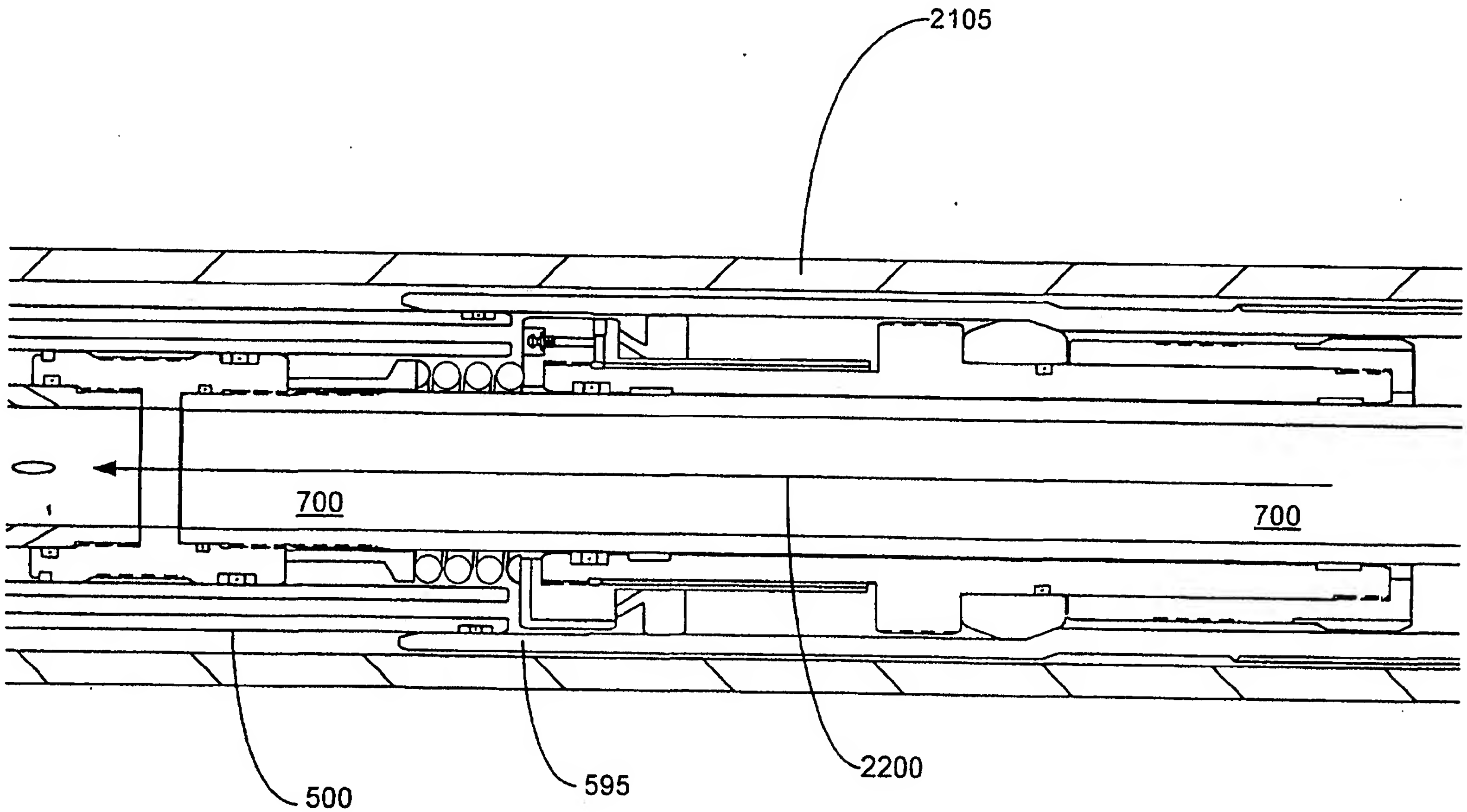

FIGURE 4C

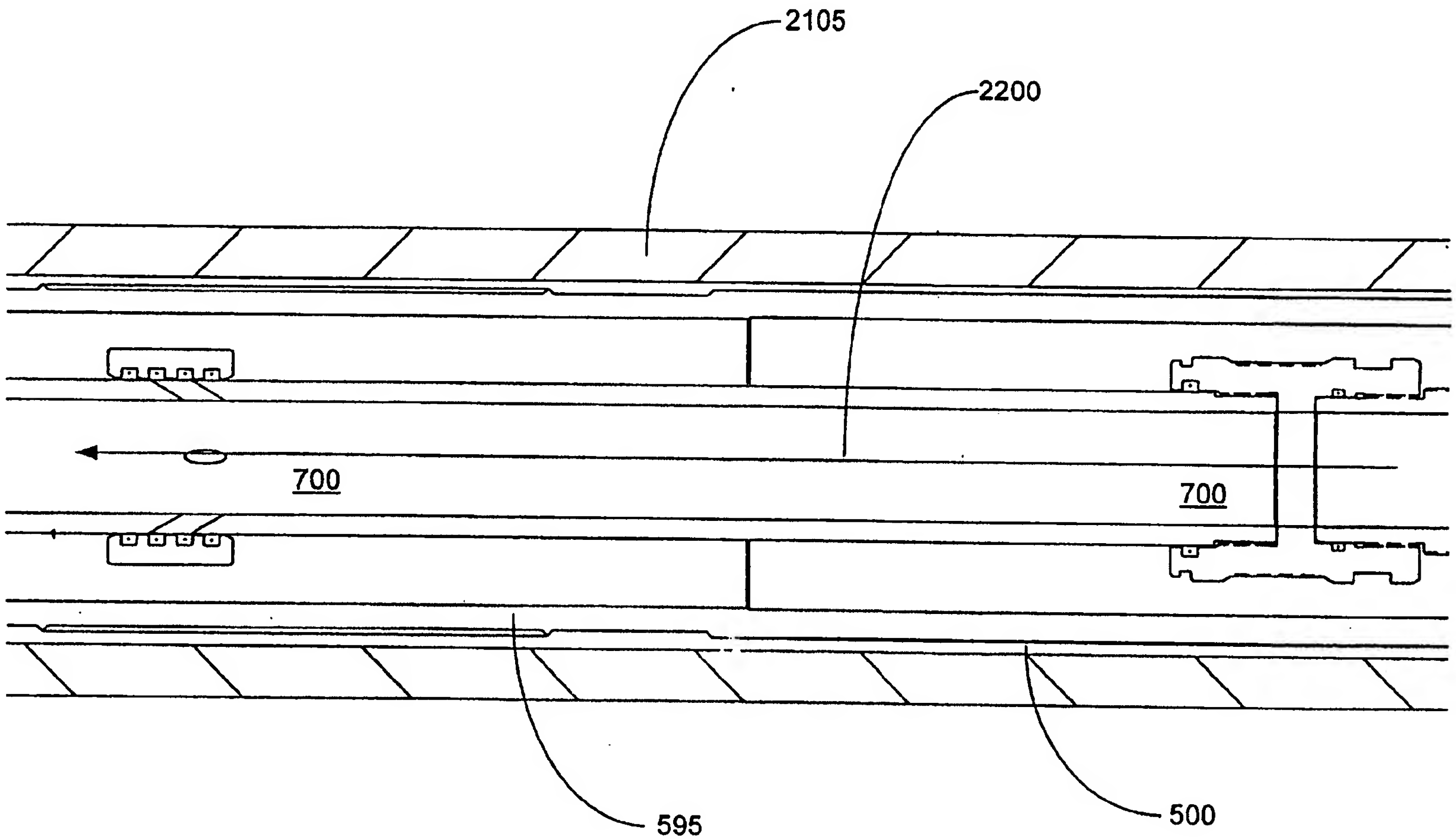

FIGURE 4D

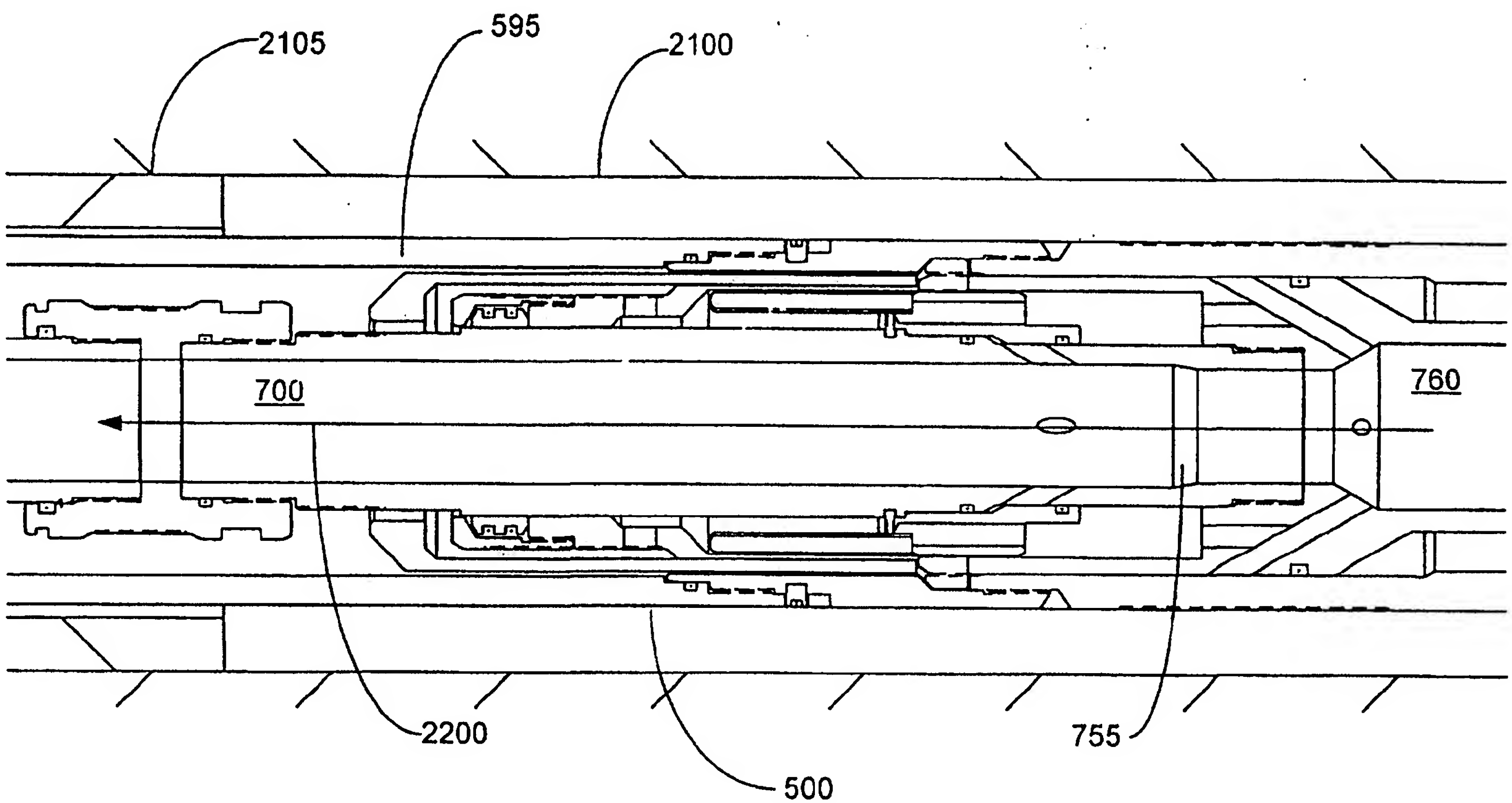

FIGURE 4E

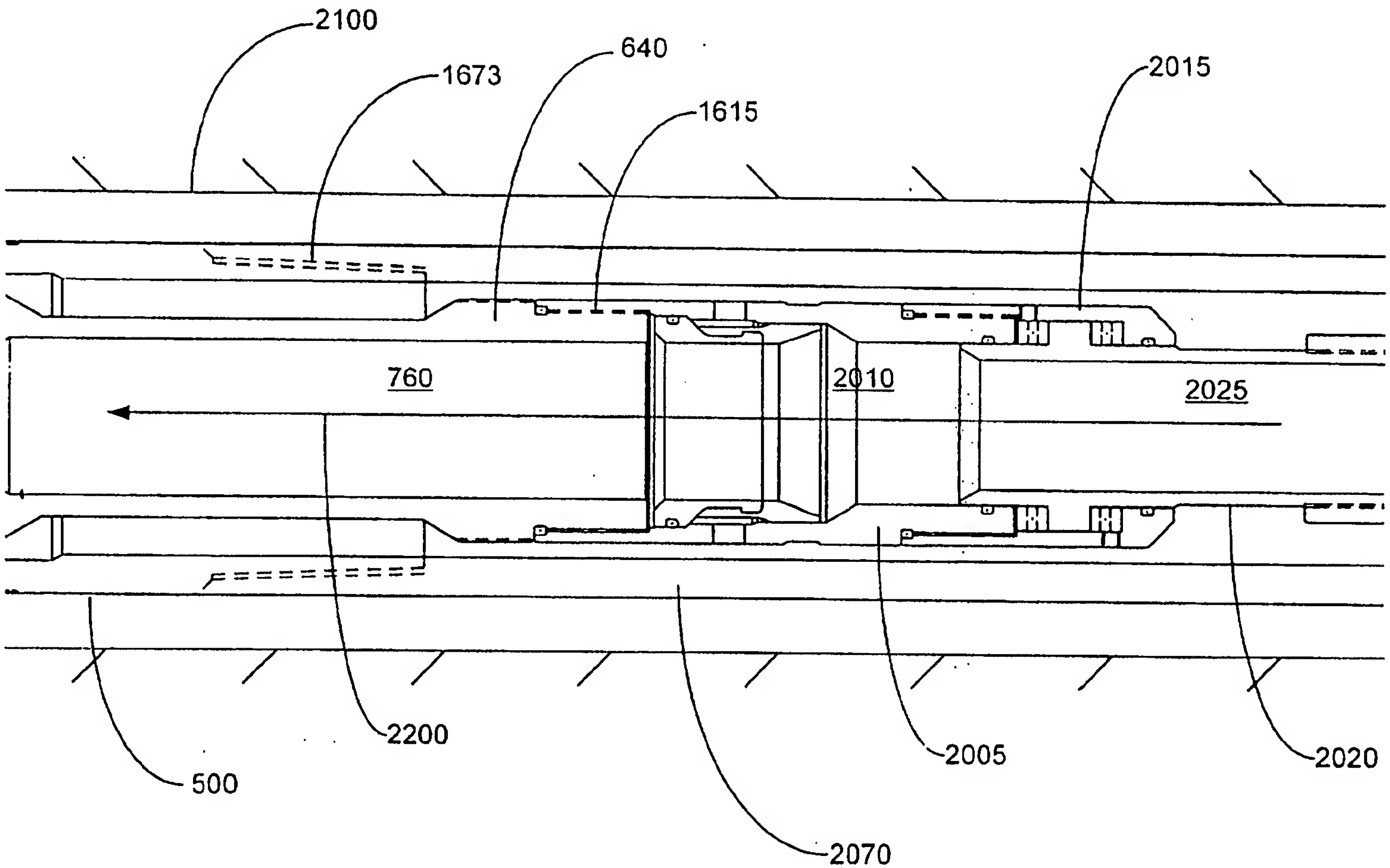

FIGURE 4F

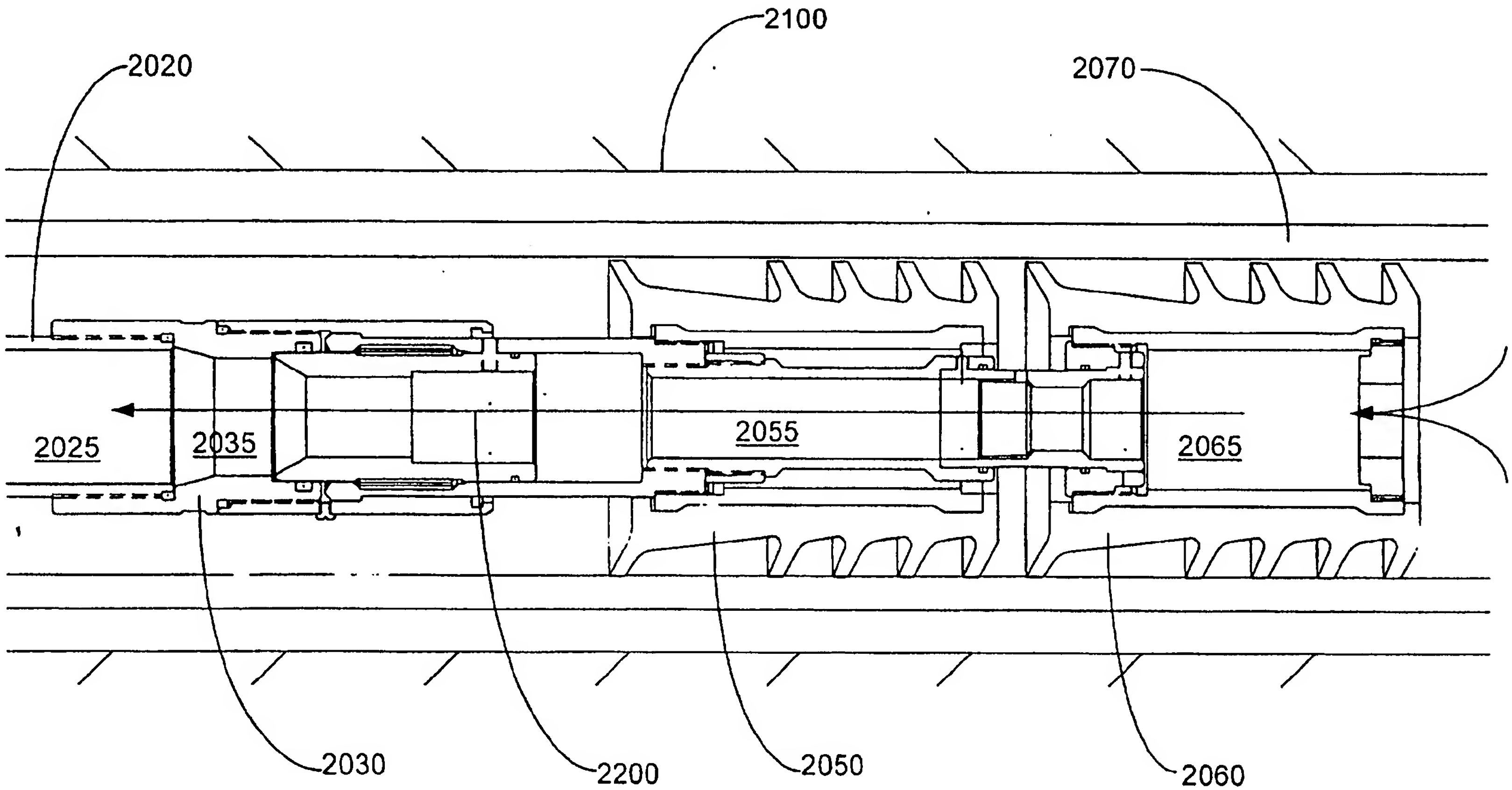

FIGURE 4G

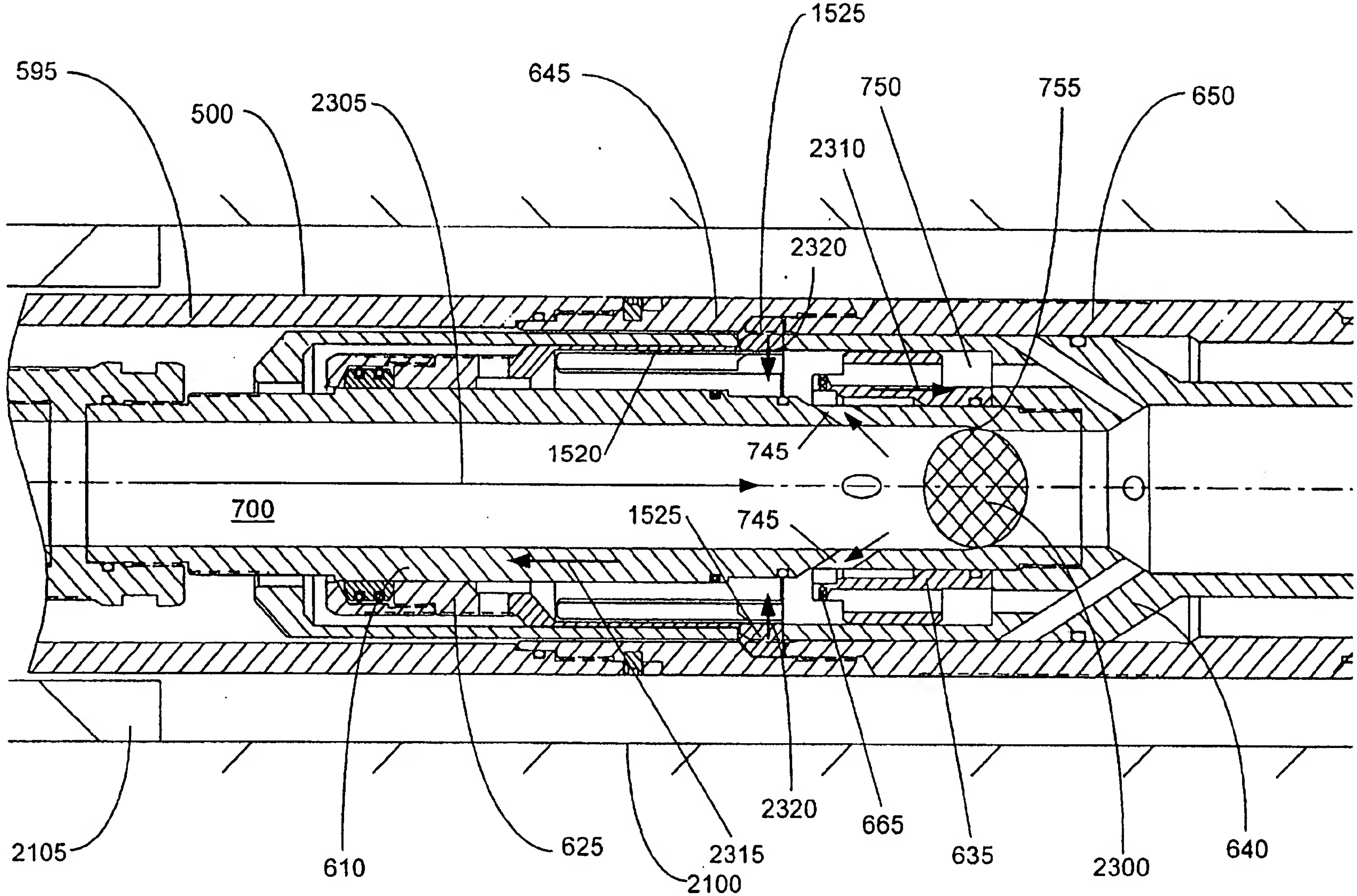
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FIGURE 5A

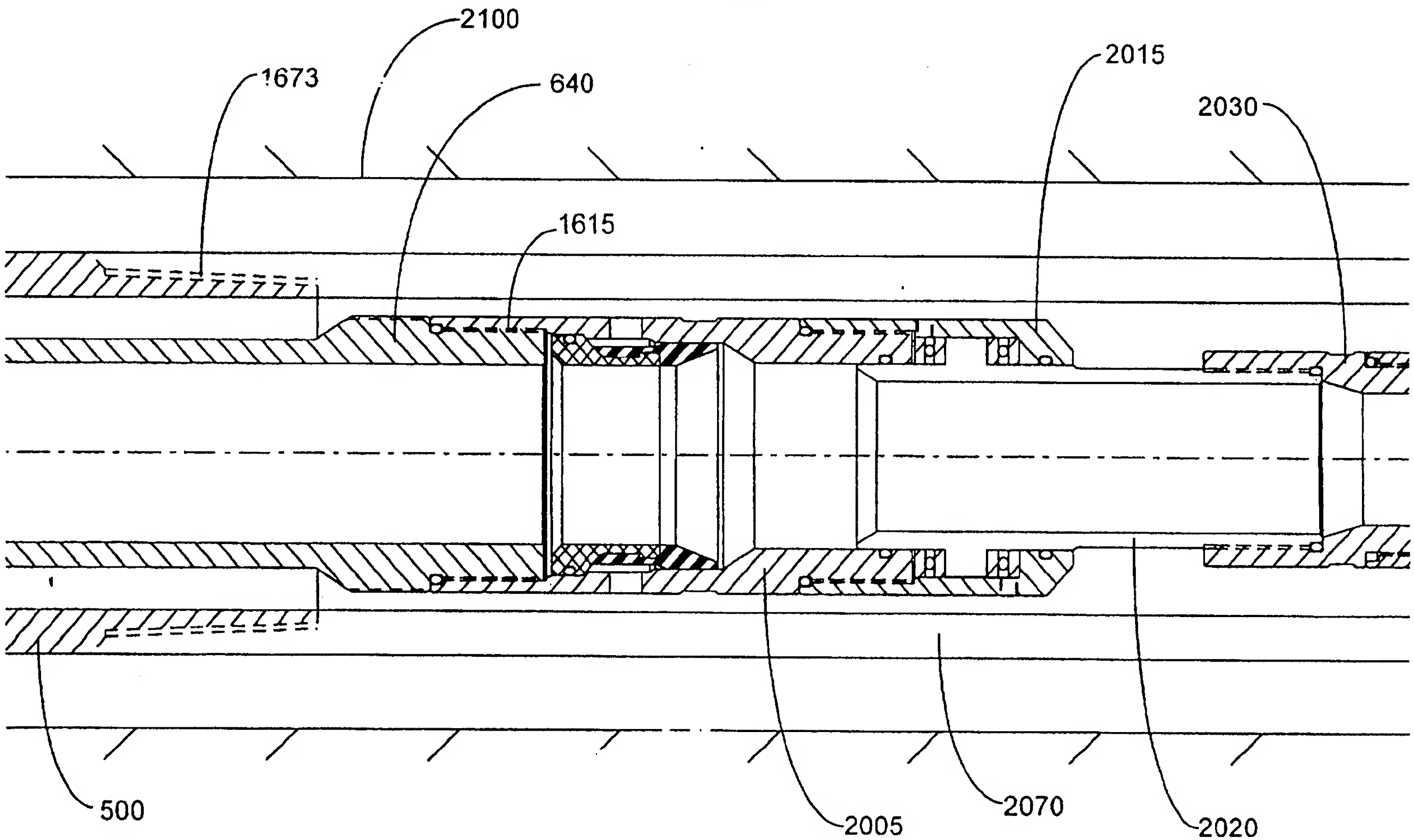

FIGURE 5B

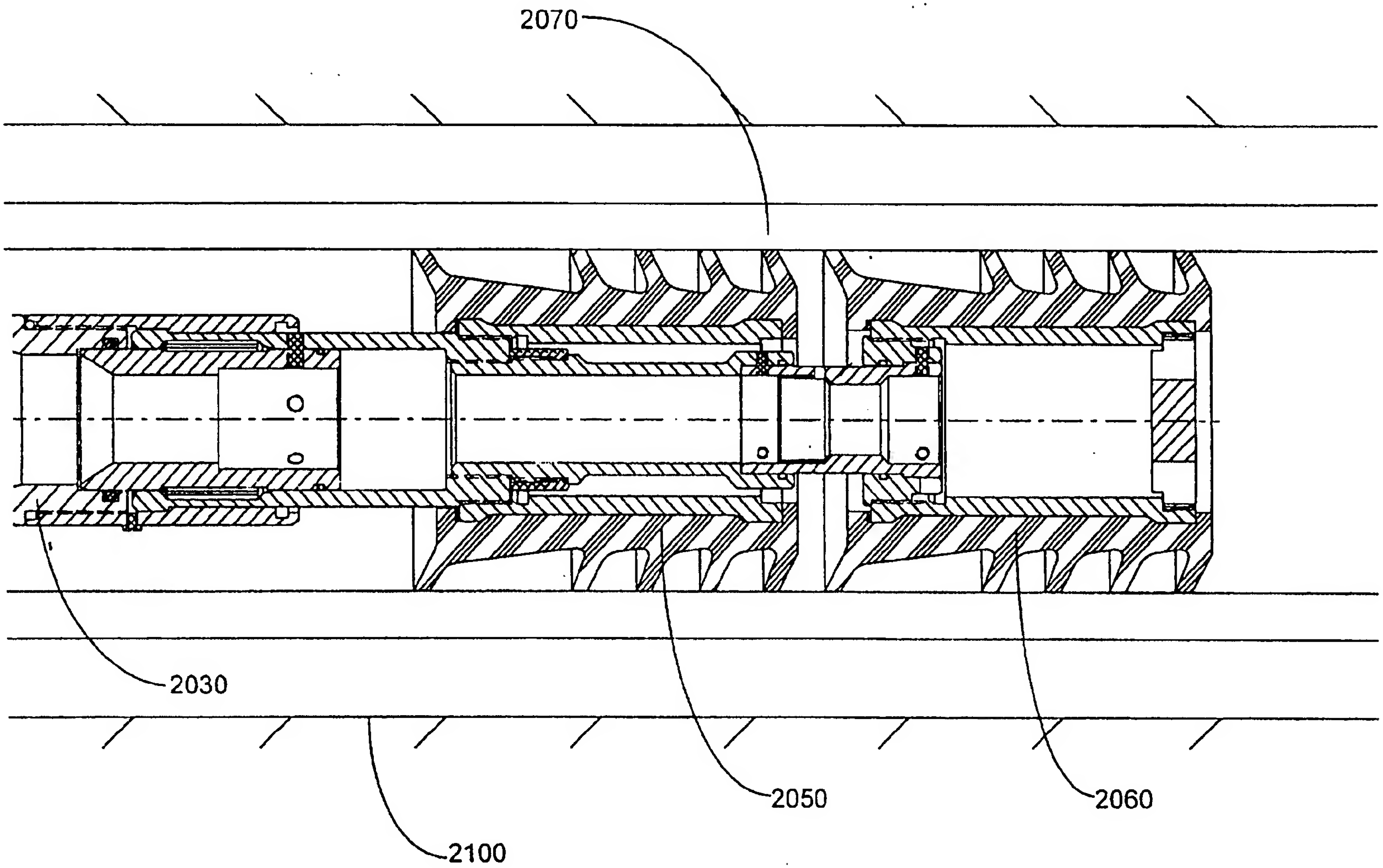

FIGURE 5C

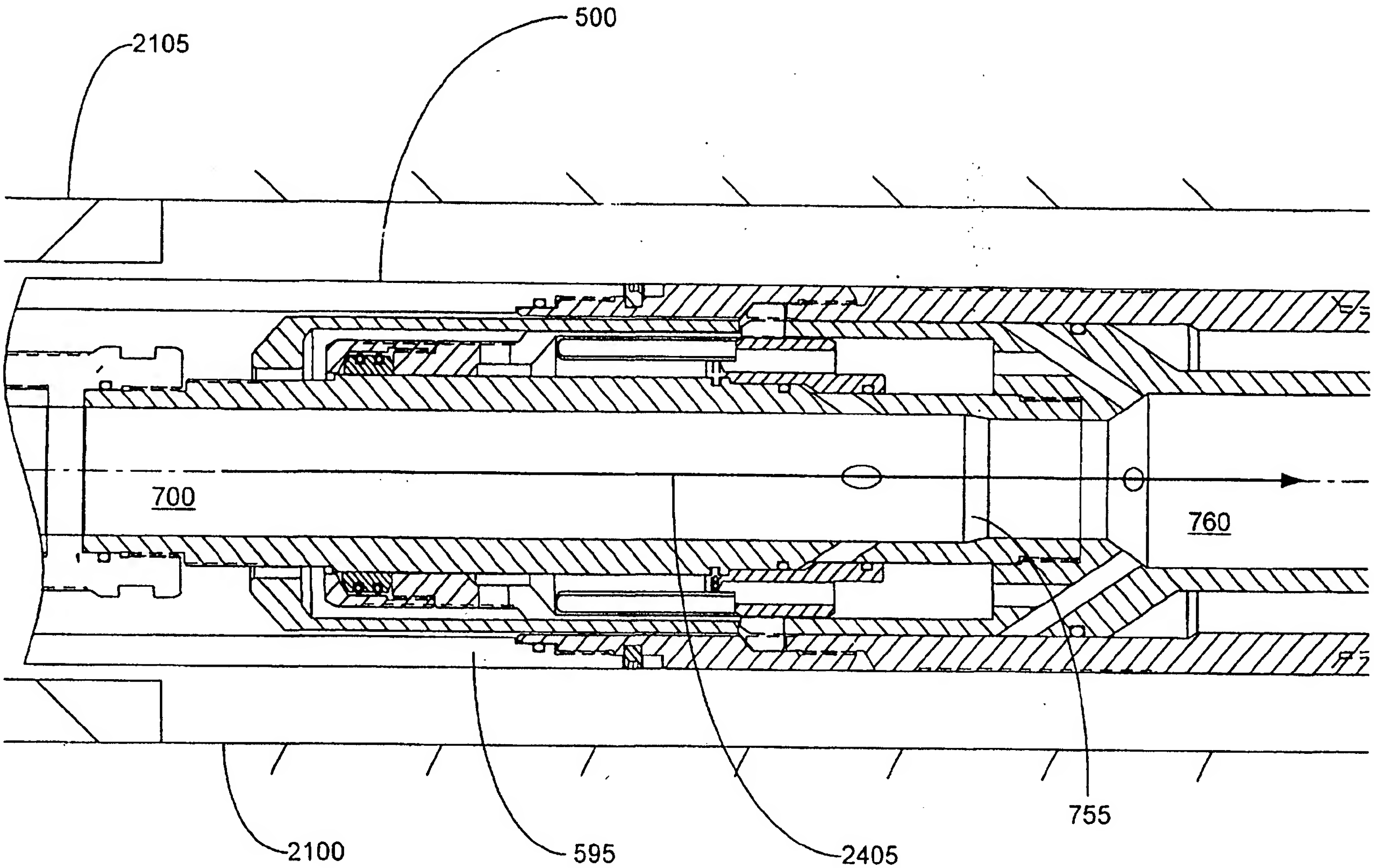

FIGURE 6A

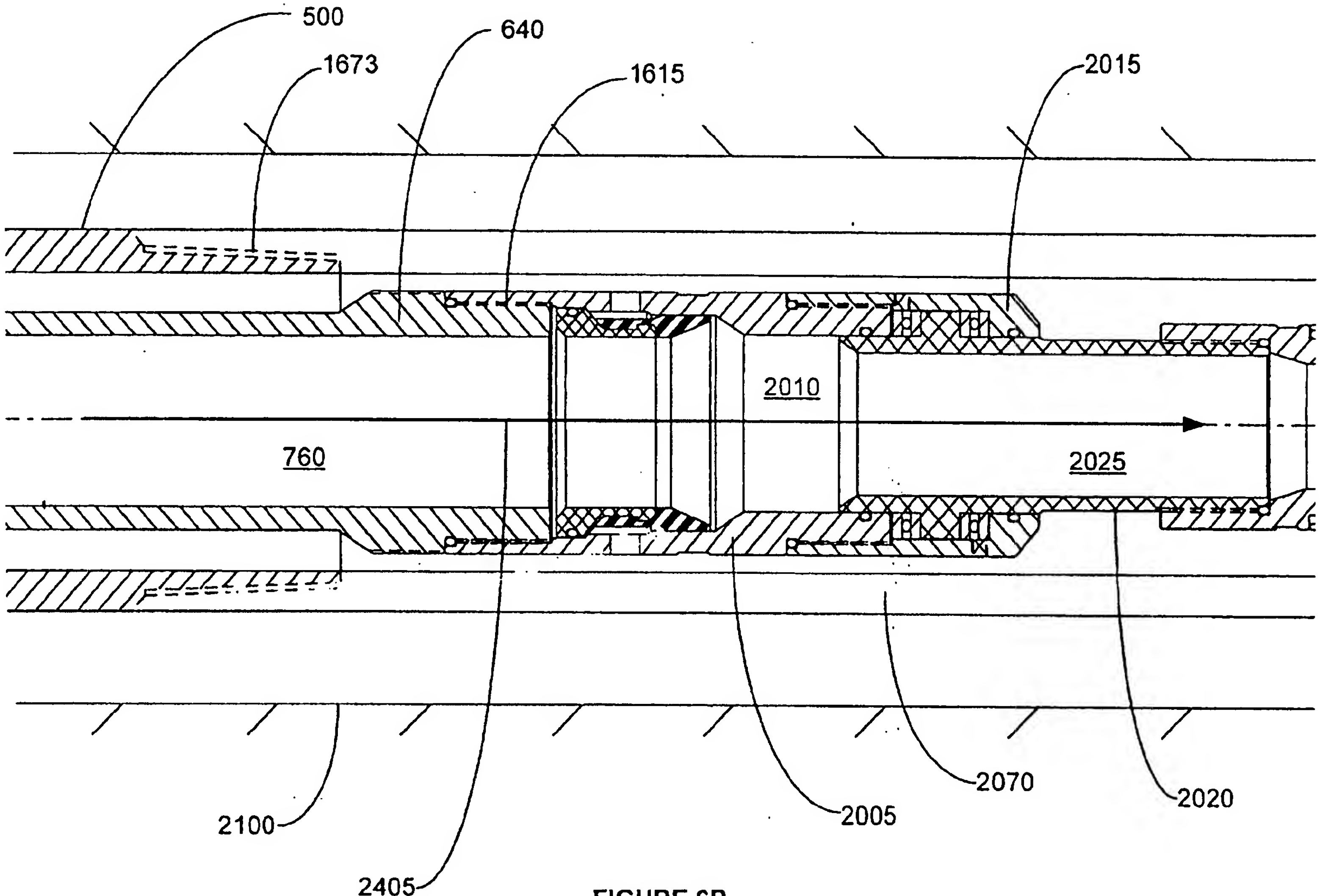

FIGURE 6B

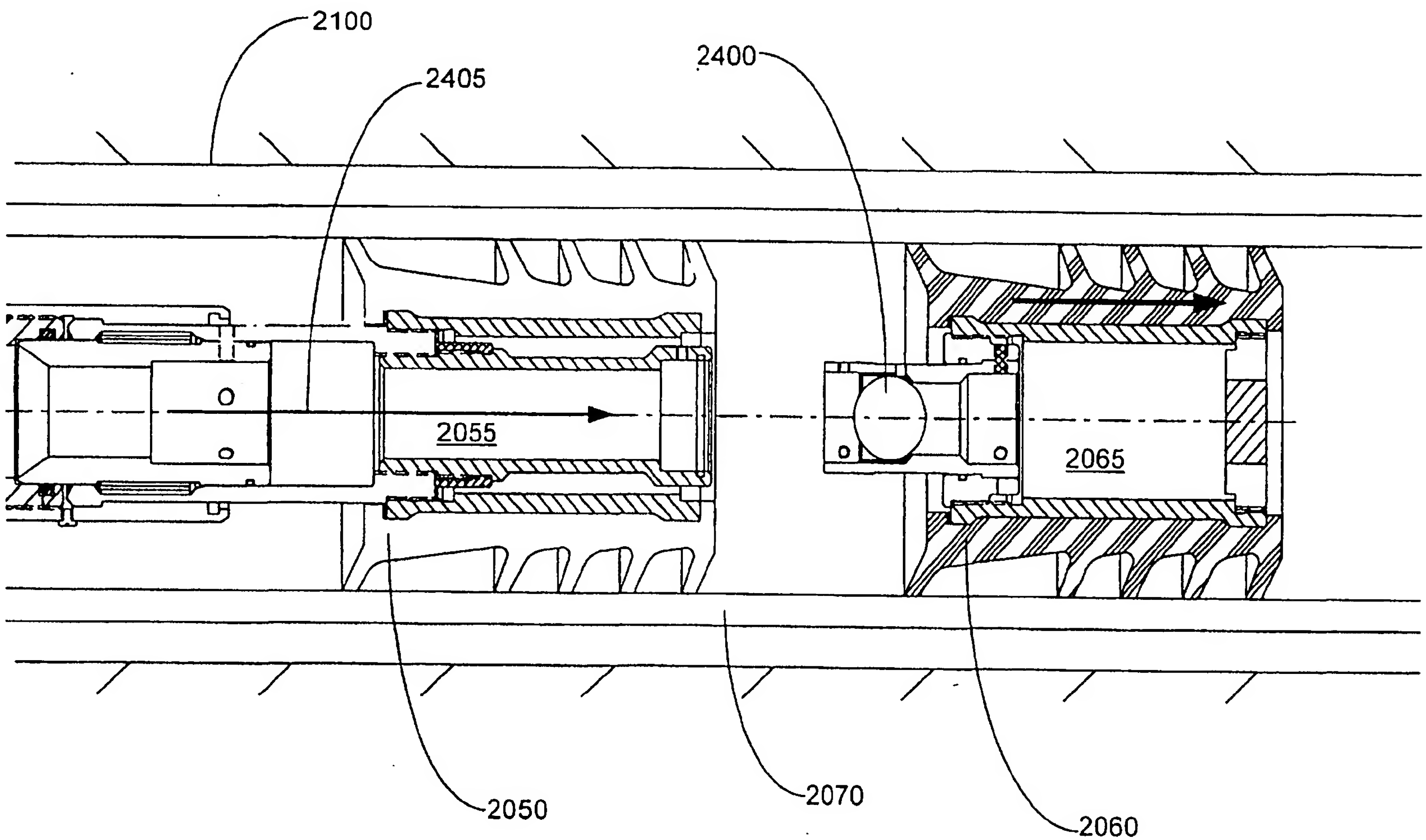

FIGURE 6C

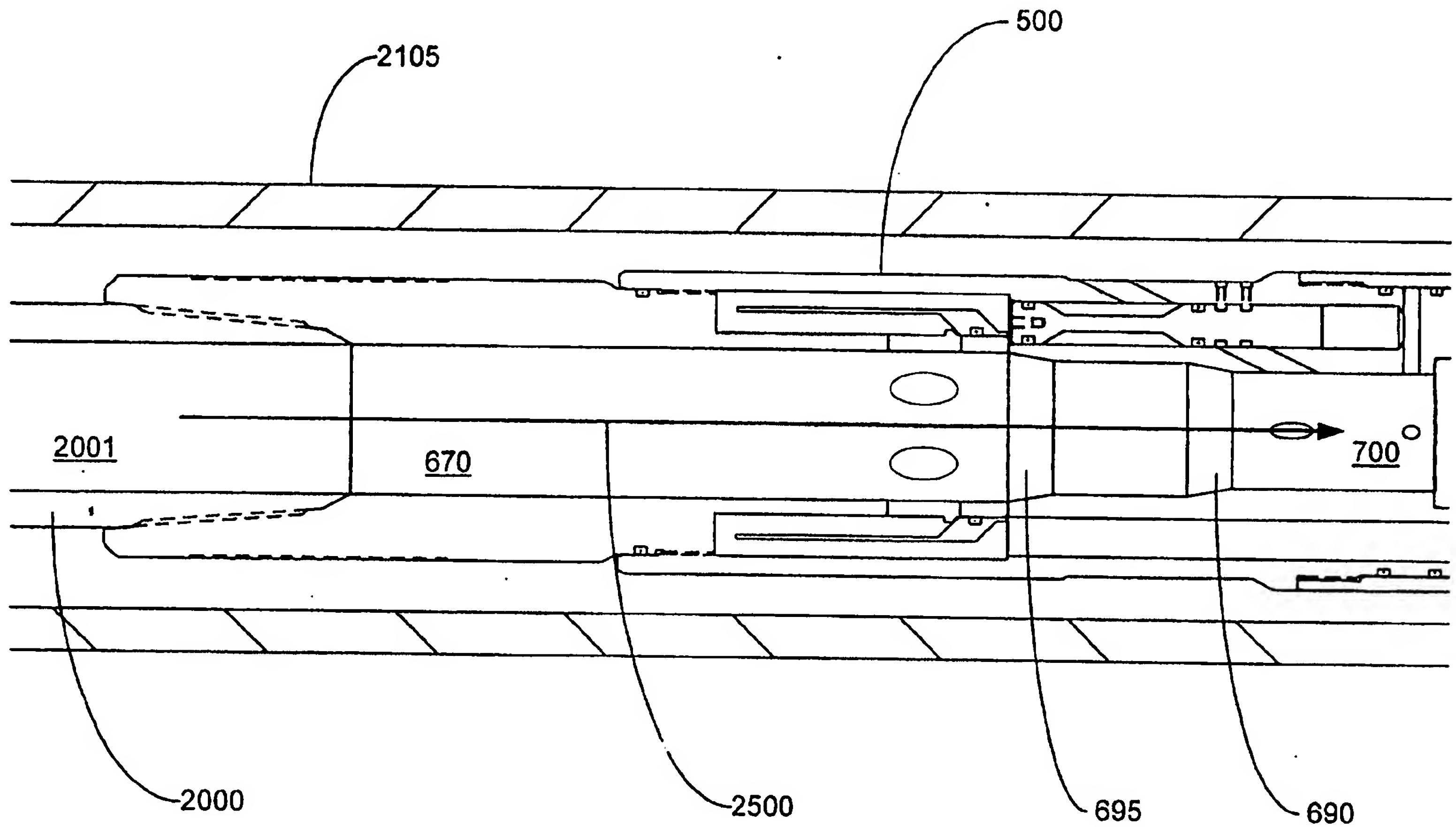

FIGURE 7A

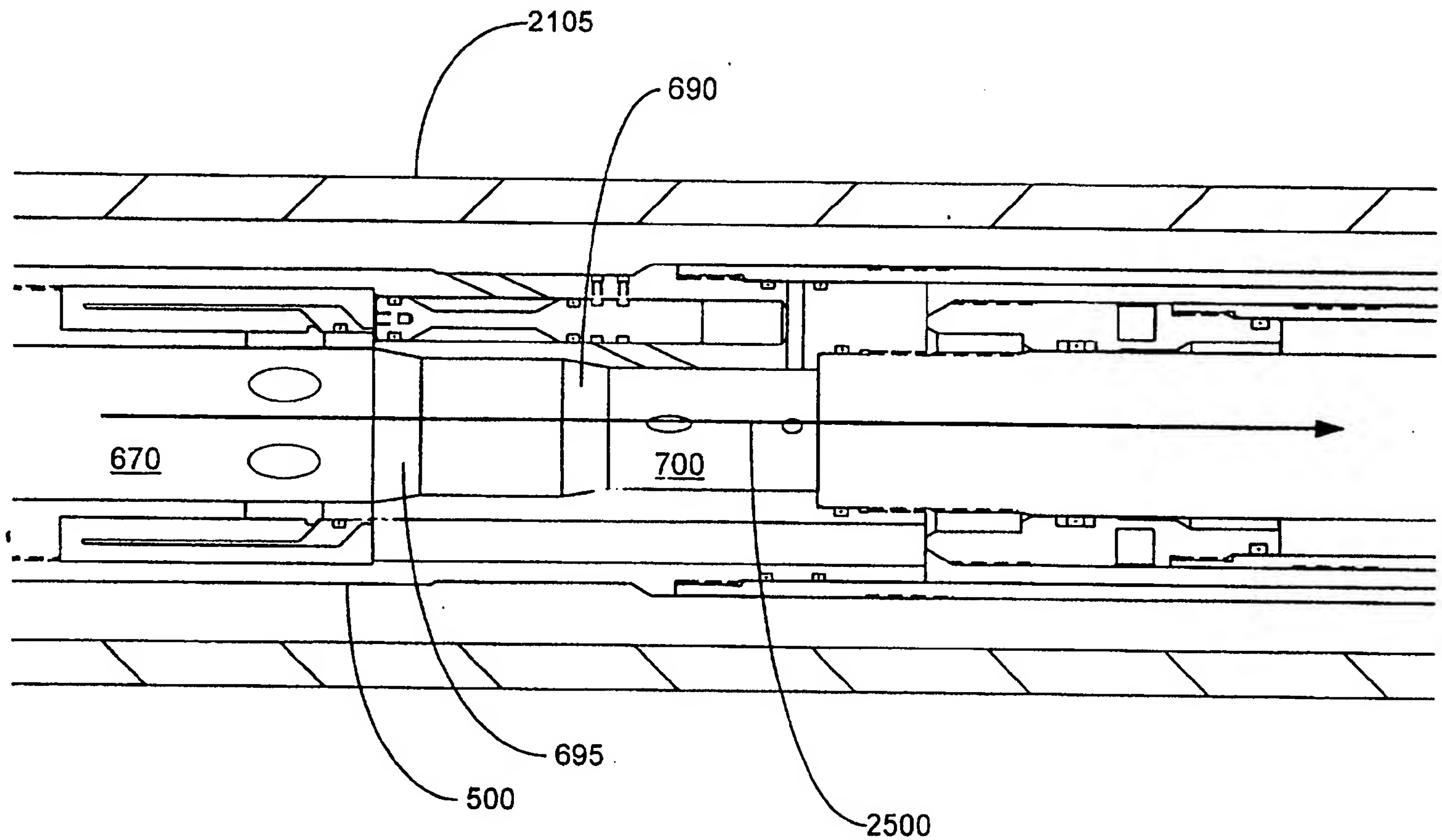

FIGURE 7B

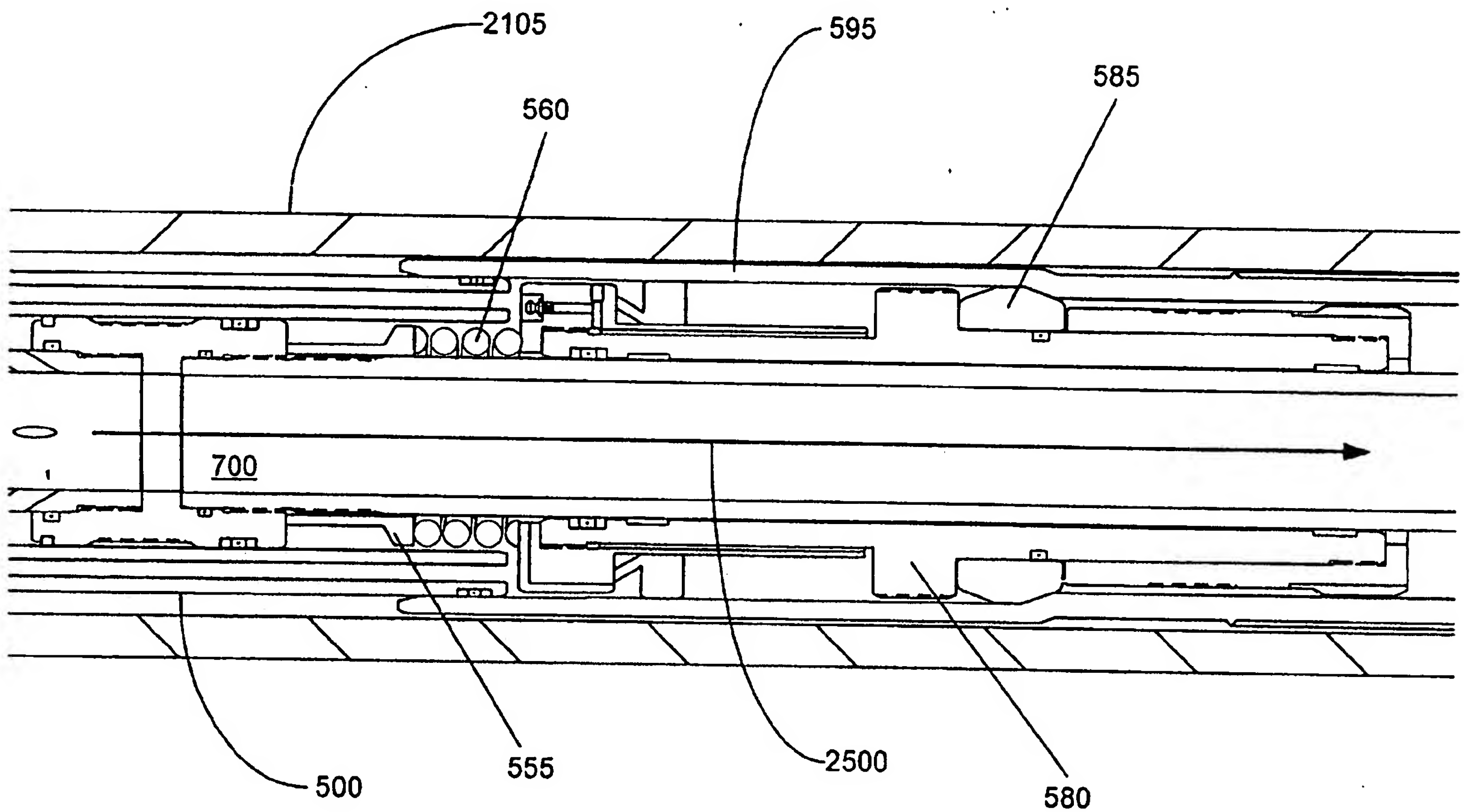

FIGURE 7C

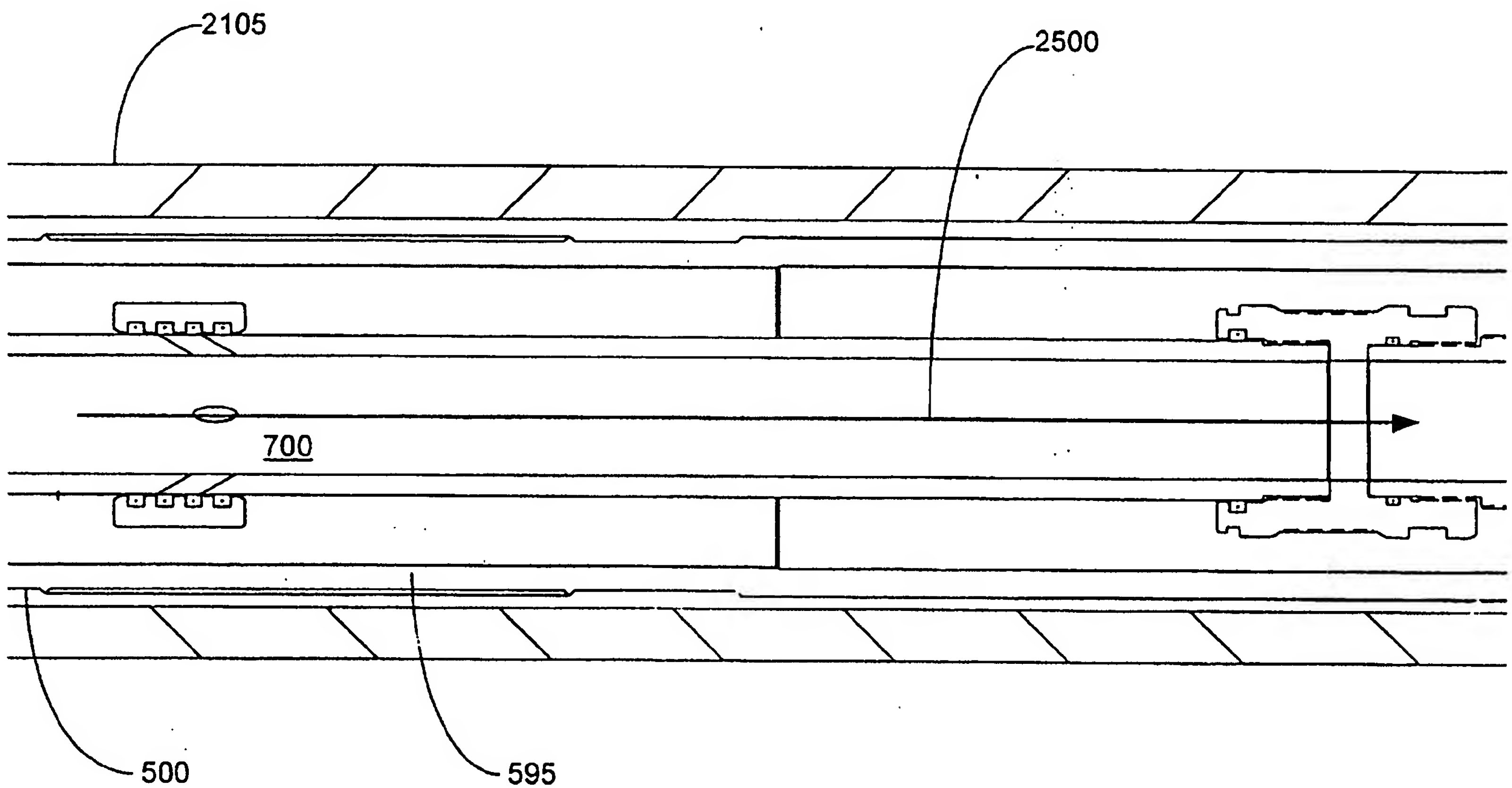

FIGURE 7D

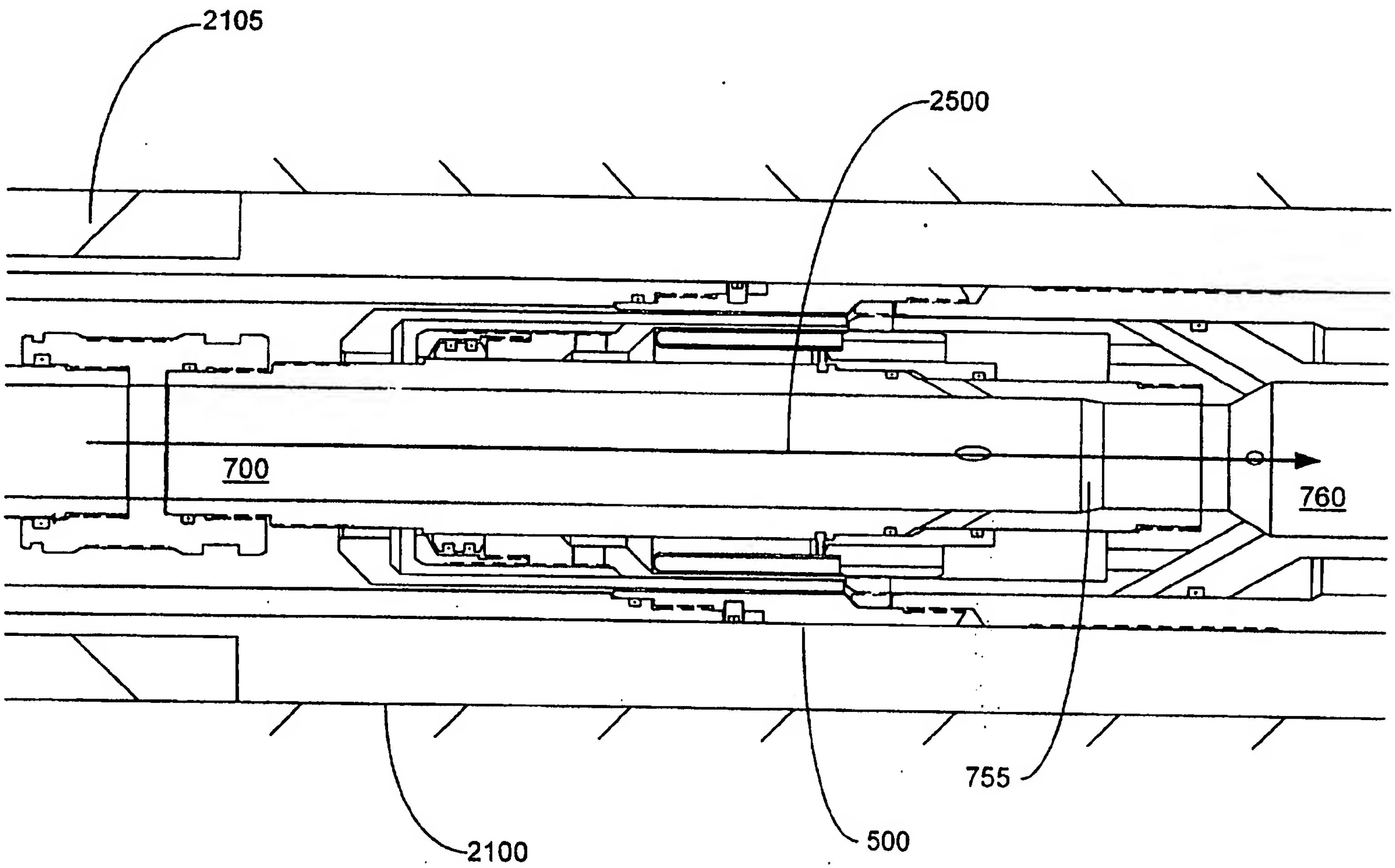

FIGURE 7E

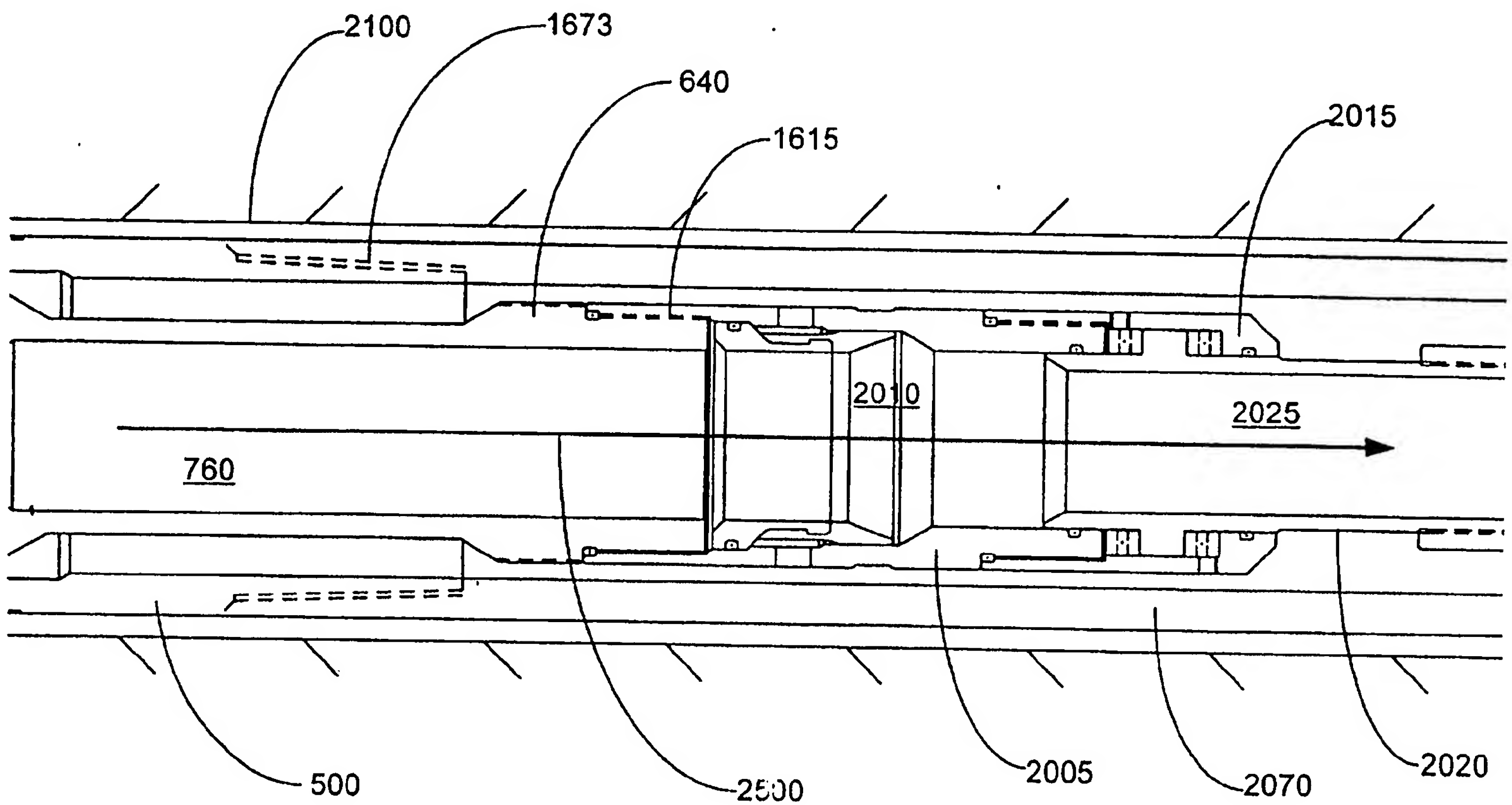

FIGURE 7F

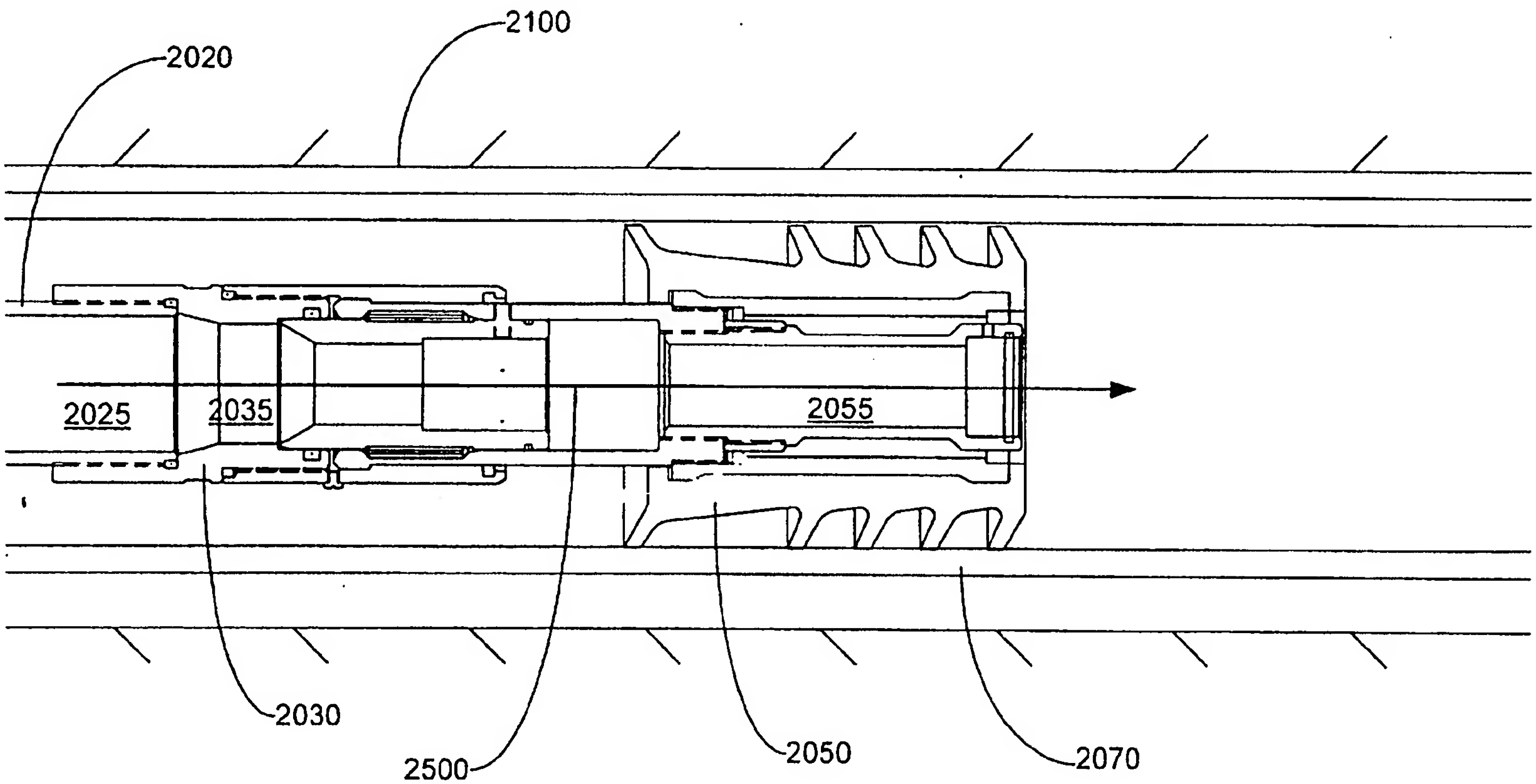

FIGURE 7G

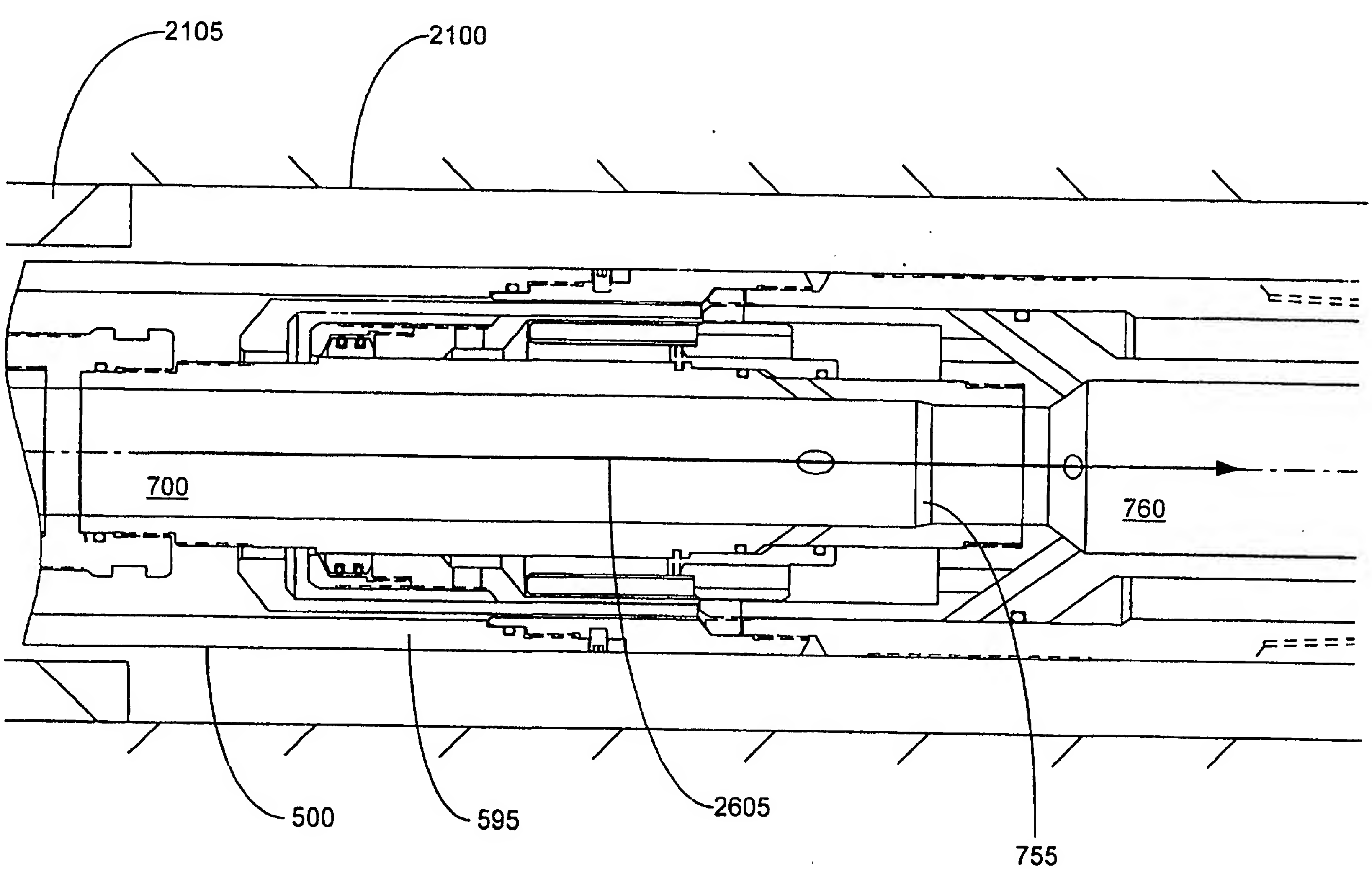

FIGURE 8A

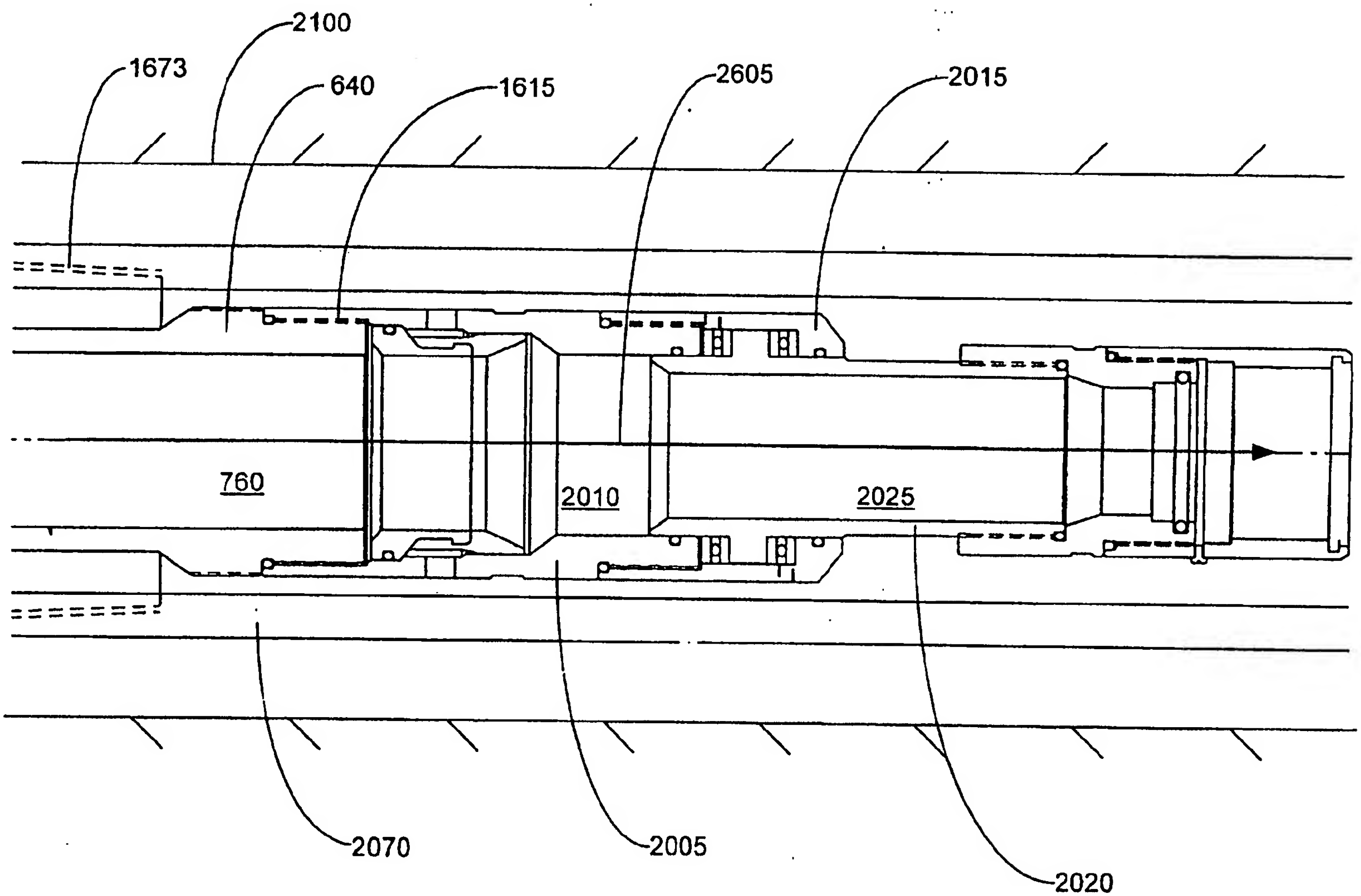

FIGURE 8B

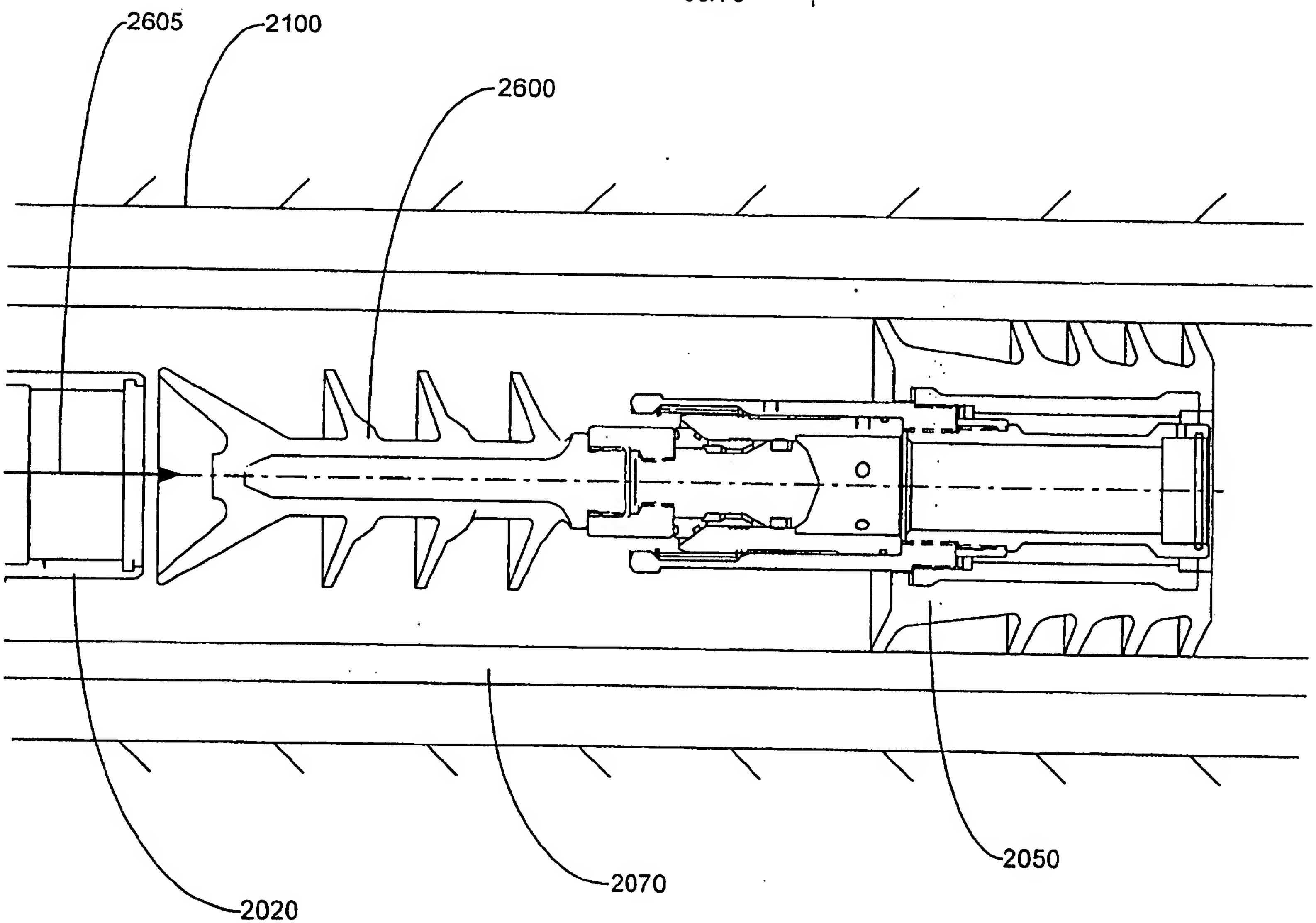

FIGURE 8C

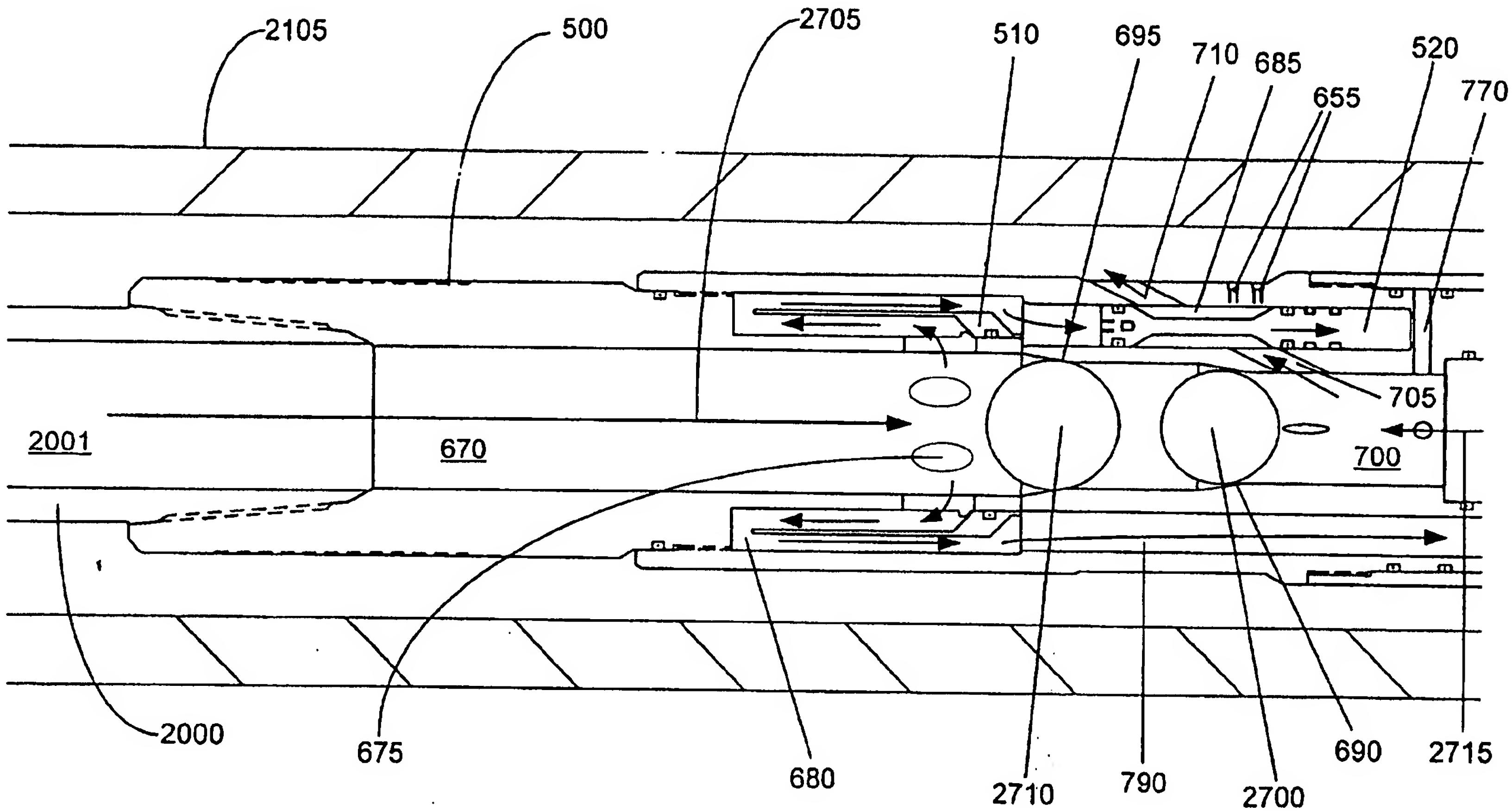
2105
500
2705
510
695
710
685
655
520
770
705
2001
670
700
2000
675
680
2710
790
2700
690
2715

FIGURE 9A

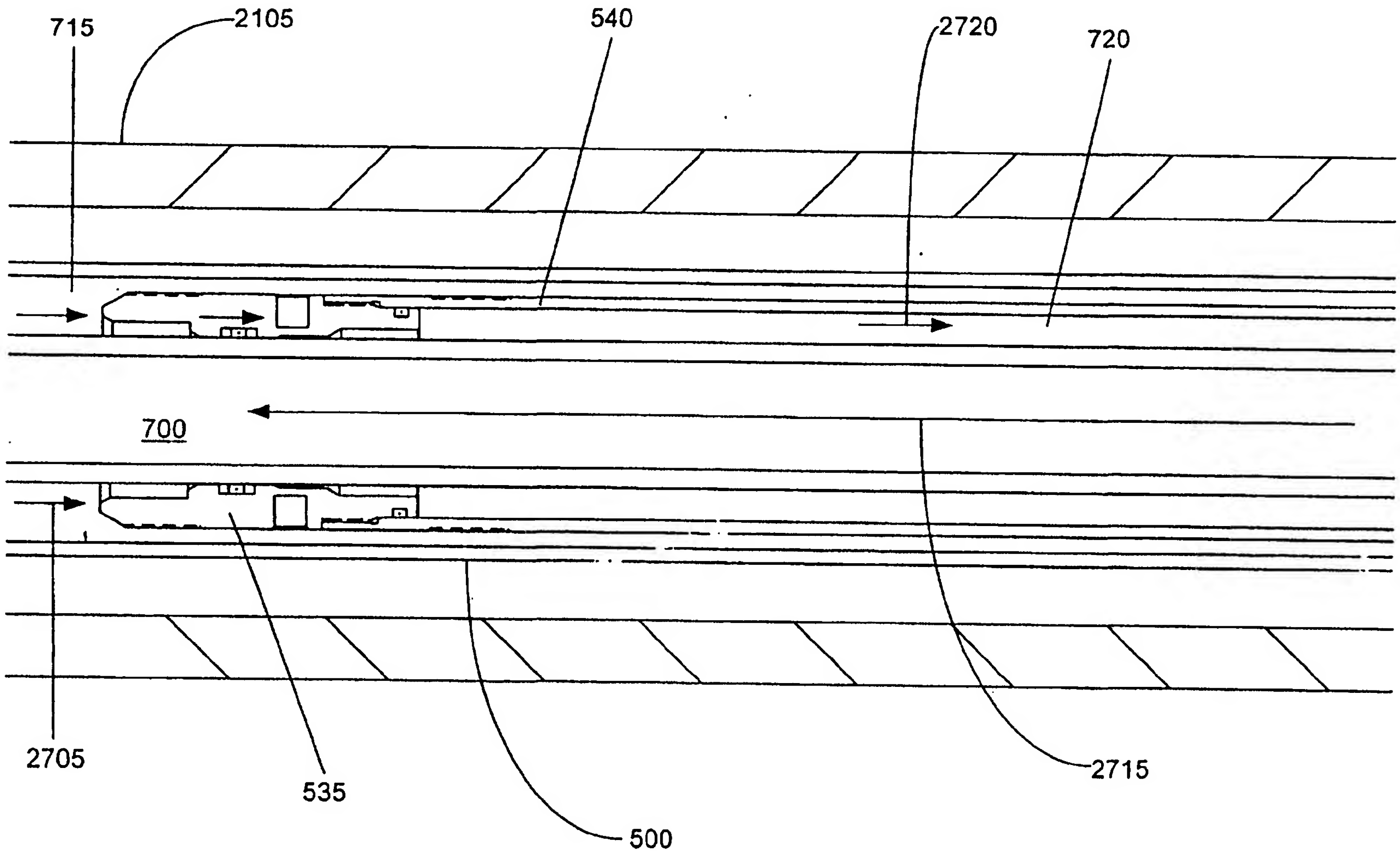

FIGURE 9B

passage 680. In this manner, the crossover valve shear pins 655 are sheared and the crossover valve members 520 are displaced. The displacement of the crossover valve members 520 causes the corresponding inner and outer crossover ports, 705 and 710, to be fluidicly coupled. The crossover valve chambers 685 are preferably pressurized by closing the primary and/or the secondary throat passages, 690 and 695, using conventional plugs or balls, and then injecting fluidic materials into the first, second and third passages 670, 675 and 680.

The primary throat passage 690 is fluidicly coupled to the secondary throat passage 695 and the fourth passage 700. The primary throat passage 690 is preferably defined by a transitionary section of the interior of the second support member 515 in which the inside diameter transitions from a first inside diameter to a second, and smaller, inside diameter. The primary throat passage 690 is preferably adapted to receive and mate with a conventional ball or plug. In this manner, the first passage 670 optimally fluidicly isolated from the fourth passage 700.

The secondary throat passage 695 is fluidicly coupled to the first passage 670 and the primary throat passage 695. The secondary throat passage 695 is preferably defined by another transitionary section of the interior of the second support member 515 in which the inside diameter transitions from a first inside diameter to a second, and smaller, inside diameter. The secondary throat passage 695 is preferably adapted to receive and mate with a conventional ball or plug. In this manner, the first passage 670 optimally fluidicly isolated from the fourth passage 700.

The inside diameter of the primary throat passage 690 is preferably less than or equal to the inside diameter of the secondary throat passage 695. In this manner, if required, a primary plug or ball can be placed in the primary throat passage 690, and then a larger secondary plug or ball can be placed in the secondary throat passage 695. In this manner, the first passage 670 is optimally fluidicly isolated from the fourth passage 700.

The fourth passage 700 is fluidicly coupled to the primary throat passage 690, the seventh passage 770, the force multiplier exhaust passages 725, the collet release ports 745, and the collet release throat passage 755. The fourth passage 700 is preferably defined by the interiors of the second support member 515, the force multiplier inner support member 530, the first coupling 545, the third support member 550, the second coupling 605, and the collet mandrel 610. The fourth passage 700 is preferably adapted to convey fluidic materials such as, for example, drilling mud, cement, and/or lubricants. The fourth passage 700 is preferably adapted to convey fluidic materials at operating pressures and flow rates ranging from about 0 to 10,000 psi and 0 to 650 gallons/minute.

The inner crossover ports 705 are fluidicly coupled to the fourth passage 700 and the corresponding crossover valve chambers 685. The inner crossover ports 705 are preferably defined by substantially radial openings provided in an interior wall of the second support member 515. The inner crossover ports 705 are preferably adapted to convey fluidic materials such as, for example, drilling mud, cement, and lubricants. The inner crossover ports 705 are preferably adapted to convey fluidic materials at operating pressures and flow rates ranging from about 0 to 10,000 psi and 0 to 50 gallons/minute.

During operation of the apparatus 500, preferably the inner crossover ports 705 are controllably fluidicly coupled to the corresponding crossover valve chambers 685 and outer crossover ports 710 by displacement of the corresponding crossover valve members 520. In this manner, fluidic materials within the fourth passage 700 are exhausted to the exterior of the apparatus 500.

The outer crossover ports 710 are fluidicly coupled to corresponding crossover valve chambers 685 and the exterior of the apparatus 500. The outer crossover ports 710 are preferably defined by substantially radial openings provided in an exterior wall of the second support member 515. The outer crossover ports 710 are preferably adapted to convey fluidic materials such as, for example, drilling mud, cement, and

lubricants. The outer crossover ports 710 are preferably adapted to convey fluidic materials at operating pressures and flow rates ranging from about 0 to 10,000 psi and 0 to 50 gallons/minute.

During operation of the apparatus 500, preferably the outer crossover ports 710 are controllably fluidicly coupled to the corresponding crossover valve chambers 685 and inner crossover ports 705 by displacement of the corresponding crossover valve members 520. In this manner, fluidic materials within the fourth passage 700 are exhausted to the exterior of the apparatus 500.

The force multiplier piston chamber 715 is fluidicly coupled to the third passage 680. The force multiplier piston chamber 715 is preferably defined by the annular region defined by the radial gap between the force multiplier inner support member 530 and the force multiplier outer support member 525 and the axial gap between the end of the second support member 515 and the end of the lubrication fitting 565.

During operation of the apparatus, preferably the force multiplier piston chamber 715 is pressurized to operating pressures ranging from about 0 to 10,000 psi. The pressurization of the force multiplier piston chamber 715 preferably displaces the force multiplier piston 535 and the force multiplier sleeve 540. The displacement of the force multiplier piston 535 and the force multiplier sleeve 540 in turn preferably displaces the mandrel 580 and expansion cone 585. In this manner, the liner hanger 595 is radially expanded. The pressurization of the force multiplier piston chamber 715 preferably directly displaces the mandrel 580 and the expansion cone 585. In this manner, the force multiplier piston 535 and the force multiplier sleeve 540 may be omitted. The lubrication fitting 565 preferably further includes one or more slots 566 for facilitating the passage of pressurized fluids to act directly upon the mandrel 580 and expansion cone 585.

The force multiplier exhaust chamber 720 is fluidicly coupled to the force multiplier exhaust passages 725. The force multiplier exhaust chamber 720 is preferably defined by the annular region defined by the radial gap between the force

multiplier inner support member 530 and the force multiplier sleeve 540 and the axial gap between the force multiplier piston 535 and the first coupling 545. During operation of the apparatus 500, preferably fluidic materials within the force multiplier exhaust chamber 720 are exhausted into the fourth passage 700 using the force multiplier exhaust passages 725. In this manner, during operation of the apparatus 500, the pressure differential across the force multiplier piston 535 is substantially equal to the difference in operating pressures between the force multiplier piston chamber 715 and the fourth passage 700.

The force multiplier exhaust passages 725 are fluidicly coupled to the force multiplier exhaust chamber 720 and the fourth passage 700. The force multiplier exhaust passages 725 are preferably defined by substantially radial openings provided in the second end 1160 of the force multiplier inner support member 530.

The second annular chamber 735 is fluidicly coupled to the third annular chamber 750. The second annular chamber 735 is preferably defined by the annular region defined by the radial gap between the third support member 550 and the liner hanger 595 and the axial gap between the centralizer 590 and the collet assembly 625. During operation of the apparatus 500, preferably fluidic materials displaced by movement of the mandrel 580 and expansion cone 585 are conveyed from the second annular chamber 735 to the third annular chamber 750, the sixth passages 765, and the sixth passage 760. In this manner, the operation of the apparatus 500 is optimized.

The expansion cone travel indicator ports 740 are fluidicly coupled to the fourth passage 700. The expansion cone travel indicator ports 740 are controllably fluidicly coupled to the second annular chamber 735. The expansion cone travel indicator ports 740 are preferably defined by radial openings in the third support member 550. During operation of the apparatus 500, preferably the expansion cone travel indicator ports 740 are further controllably fluidicly coupled to the force multiplier piston chamber 715 by displacement of the travel port sealing sleeve 600 caused by axial displacement of the mandrel 580 and expansion cone 585. In this manner, the completion of the radial

expansion process is indicated by a pressure drop caused by fluidicly coupling the force multiplier piston chamber 715 with the fourth passage 700.

The collet release ports 745 are fluidicly coupled to the fourth passage 700 and the collet sleeve release chamber 805. The collet release ports 745 are controllably fluidicly coupled to the second and third annular chambers, 735 and 750. The collet release ports 745 are defined by radial openings in the collet mandrel 610. During operation of the apparatus 500, preferably the collet release ports 745 are controllably pressurized by blocking the collet release throat passage 755 using a conventional ball or plug. The pressurization of the collet release throat passage 755 in turn pressurizes the collet sleeve release chamber 805. The pressure differential between the pressurized collet sleeve release chamber 805 and the third annular chamber 750 then preferably shears the collet shear pins 665 and displaces the collet retaining sleeve 635 in the axial direction.

The third annular chamber 750 is fluidicly coupled to the second annular chamber 735 and the sixth passages 765. The third annular chamber 750 is controllably fluidicly coupled to the collet release ports 745. The third annular chamber 750 is preferably defined by the annular region defined by the radial gap between the collet mandrel 610 and the collet assembly 625 and the first end 1585 of the collet retaining adapter and the axial gap between the collet assembly 625 and the intermediate portion 1590 of the collet retaining adapter 640.

The collet release throat passage 755 is fluidicly coupled to the fourth passage 700 and the fifth passage 760. The collet release throat passage 755 is preferably defined by a transitionary section of the interior of the collet mandrel 610 including a first inside diameter that transitions into a second smaller inside diameter. The collet release throat passage 755 is preferably adapted to receive and mate with a conventional sealing plug or ball. In this manner, the fourth passage 700 is optimally fluidicly isolated from the fifth passage 760. The maximum inside diameter of the

collet release throat passage 755 is preferably less than or equal to the minimum inside diameters of the primary and secondary throat passages, 690 and 695.

During operation of the apparatus 500, preferably a conventional sealing plug or ball is placed in the collet release throat passage 755. The fourth passage 700 and the collet release ports 745 are then pressurized. The pressurization of the collet release throat passage 755 in turn pressurizes the collet sleeve release chamber 805. The pressure differential between the pressurized collet sleeve release chamber 805 and the third annular chamber 750 then preferably shears the collet shear pins 665 and displaces the collet retaining sleeve 635 in the axial direction.

The fifth passage 760 is fluidicly coupled to the collet release throat passage 755 and the sixth passages 765. The fifth passage 760 is preferably defined by the interior of the second end 1595 of the collet retaining adapter 640.

The sixth passages 765 are fluidicly coupled to the fifth passage 760 and the third annular chamber 750. The sixth passages 765 are preferably defined by approximately radial openings provided in the intermediate portion 1590 of the collet retaining adapter 640. During operation of the apparatus 500, preferably the sixth passages 765 fluidicly couple the third annular passage 750 to the fifth passage 760. In this manner, fluidic materials displaced by axial movement of the mandrel 580 and expansion cone 585 are exhausted to the fifth passage 760.

The seventh passages 770 are fluidicly coupled to corresponding crossover valve chambers 685 and the fourth passage 700. The seventh passages 770 are preferably defined by radial openings in the intermediate portion 1065 of the second support member 515. During operation of the apparatus 700, the seventh passage 770 preferably maintain the rear portions of the corresponding crossover valve chamber 685 at the same operating pressure as the fourth passage 700. In this manner, the pressure differential across the crossover valve members 520 caused by blocking the primary and/or the secondary throat passages, 690 and 695, is optimally maintained.

The collet sleeve passages 775 are fluidicly coupled to the second annular chamber 735 and the third annular chamber 750. The collet sleeve passages 775 are preferably adapted to convey fluidic materials between the second annular chamber 735 and the third annular chamber 750. The collet sleeve passages 735 are preferably defined by axial openings provided in the collet sleeve 635.

The force multiplier supply passages 790 are fluidicly coupled to the third passage 680 and the force multiplier piston chamber 715. The force multiplier supply passages 790 are preferably defined by a plurality of substantially axial openings in the second support member 515. During operation of the apparatus 500, the force multiplier supply passages 790 preferably convey pressurized fluidic materials from the third passage 680 to the force multiplier piston chamber 715.

The first lubrication supply passage 795 is fluidicly coupled to the lubrication fitting 1285 and the body of lubricant 575. The first lubrication supply passage 795 is preferably defined by openings provided in the lubrication fitting 565 and the annular region defined by the radial gap between the lubrication fitting 565 and the mandrel 580. During operation of the apparatus 500, the first lubrication passage 795 is preferably adapted to convey lubricants from the lubrication fitting 1285 to the body of lubricant 575.

The second lubrication supply passage 800 is fluidicly coupled to the body of lubricant 575 and the expansion cone 585. The second lubrication supply passage 800 is preferably defined by the annular region defined by the radial gap between the expansion mandrel 580 and the liner hanger 595. During operation of the apparatus 500, the second lubrication passage 800 is preferably adapted to convey lubricants from the body of lubricant 575 to the expansion cone 585. In this manner, the dynamic interface between the expansion cone 585 and the liner hanger 595 is optimally lubricated.

The collet sleeve release chamber 805 is fluidicly coupled to the collet release ports 745. The collet sleeve release chamber 805 is preferably defined by the annular

region bounded by the recess 1455 and the second shoulder 1575. During operation of the apparatus 500, the collet sleeve release chamber 805 is preferably controllably pressurized. This manner, the collet release sleeve 635 is axially displaced.

Referring to FIGS. 4A to 4G, during operation of the apparatus 500, the apparatus 500 is coupled to an annular support member 2000 having an internal passage 2001, a first coupling 2005 having an internal passage 2010, a second coupling 2015, a third coupling 2020 having an internal passage 2025, a fourth coupling 2030 having an internal passage 2035, a tail wiper 2050 having an internal passage 2055, a lead wiper 2060 having an internal passage 2065, and one or more tubular members 2070.

The annular support member 2000 may include any number of conventional commercially available annular support members. The annular support member 2000 preferably further includes a conventional controllable vent passage for venting fluidic materials from the internal passage 2001. In this manner, during placement of the apparatus 500 in the wellbore 2000, fluidic materials in the internal passage 2001 are vented thereby minimizing surge pressures.

The first coupling 2005 is preferably removably coupled to the second threaded portion 1615 of the collet retaining adapter 640 and the second coupling 2015. The first coupling 2005 may comprise any number of conventional commercially available couplings. The first coupling 2005 is preferably an equalizer case available from Halliburton Energy Services in order to optimally provide containment of the equalizer valve.

The second coupling 2015 is preferably removably coupled to the first coupling 2005 and the third coupling 2020. The second coupling 2015 may comprise any number of conventional commercially available couplings. The second coupling 2015 is preferably a bearing housing available from Halliburton Energy Services in order to optimally provide containment of the bearings.

The third coupling 2020 is preferably removably coupled to the second coupling 2015 and the fourth coupling 2030. The third coupling 2020 may comprise any number

of conventional commercially available couplings. The third coupling 2020 is preferably an SSR swivel mandrel available from Halliburton Energy Services in order to optimally provide for rotation of tubular members positioned above the SSR plug set.

The fourth coupling 2030 is preferably removably coupled to the third coupling 2020 and the tail wiper 2050. The fourth coupling 2030 may comprise any number of conventional commercially available couplings. The fourth coupling 2030 is preferably a lower connector available from Halliburton Energy Services in order to optimally provide a connection to a SSR plug set.

The tail wiper 2050 is preferably removably coupled to the fourth coupling 2030 and the lead wiper 2060. The tail wiper 2050 may comprise any number of conventional commercially available tail wipers. The tail wiper 2050 is preferably an SSR top plug available from Halliburton Energy Services in order to optimally provide separation of cement and drilling mud.

The lead wiper 2060 is preferably removably coupled to the tail wiper 2050. The lead wiper 2060 may comprise any number of conventional commercially available tail wipers. The lead wiper 2060 is preferably an SSR bottom plug available from Halliburton Energy Services in order to optimally provide separation of mud and cement.

The first coupling 2005, the second coupling 2015, the third coupling 2020, the fourth coupling 2030, the tail wiper 2050, and the lead wiper 2060 are preferably a conventional SSR wiper assembly available from Halliburton Energy Services in order to optimally provide separation of mud and cement.

The tubular member 2070 are coupled to the threaded portion 1673 of the liner hanger setting sleeve 650. The tubular member 2070 may include one or more tubular members. The tubular member 2070 preferably includes a plurality of conventional tubular members coupled end to end.

The apparatus 500 is then preferably positioned in a wellbore 2100 having a preexisting section of wellbore casing 2105 using the annular support member 2000.

The wellbore 2100 and casing 2105 may be oriented in any direction from the vertical to the horizontal. The apparatus 500 is preferably positioned within the wellbore 2100 with the liner hanger 595 overlapping with at least a portion of the preexisting wellbore casing 2105. During placement of the apparatus 500 within the wellbore 2100, preferably fluidic materials 2200 within the wellbore 2100 are conveyed through the internal passage 2065, the internal passage 2055, the internal passage 2035, the internal passage 2025, the internal passage 2010, the fifth passage 760, the collet release throat passage 755, the fourth passage 700, the primary throat passage 690, the secondary throat passage 695, the first passage 670, and the internal passage 2001. In this manner, surge pressures during insertion and placement of the apparatus 500 within the wellbore 2000 are minimized. The internal passage 2001 preferably further includes a controllable venting passage for conveying fluidic materials out of the internal passage 2001.

Referring to FIGS. 5A to 5C, in the event of an emergency after placement of the apparatus 500 within the wellbore 2000, the liner hanger 595, the outer collet support member 645, and the liner hanger setting sleeve 650 are decoupled from the apparatus 500 by first placing a ball 2300 within the collet release throat passage 755. A quantity of a fluidic material 2305 is then injected into the fourth passage 700, the collet release ports 745, and the collet sleeve release chamber 805. The fluidic material 2305 is preferably a non-hardenable fluidic material such as, for example, drilling mud. Continued injection of the fluidic material 2305 preferably pressurizes the collet sleeve release chamber 805. The collet sleeve release chamber 805 is preferably pressurized to operating pressures ranging from about 1,000 to 3,000 psi in order to optimally provide a positive indication of the shifting of the collet retaining sleeve 635 as indicated by a sudden pressure drop. The pressurization of the collet sleeve release chamber 805 preferably applies an axial force to the collet retaining sleeve 635. The axial force applied to the collet retaining sleeve 635 preferably shears the collet retaining sleeve shear pins 665. The collet retaining sleeve 635 then preferably is

displaced in the axial direction 2310 away from the collet upsets 1525. The collet retaining sleeve 635 is preferably axially displaced when the operating pressure within the collet sleeve release chamber 805 is greater than about 1650 psi. In this manner, the collet upsets 1525 are no longer held in place within the collet slots 1600 and 1665 by the collet retaining sleeve 635.

The collet mandrel 610 is preferably then displaced in the axial direction 2315 causing the collet upsets 1525 to be moved in a radial direction 2320 out of the collet slots 1665. The liner hanger 595, the outer collet support member 645, and the liner hanger setting sleeve 650 are thereby decoupled from the remaining portions of the apparatus 500. The remaining portions of the apparatus 500 are then removed from the wellbore 2100. In this manner, in the event of an emergency during operation of the apparatus, the liner hanger 595, the outer collet support member 645, and the liner hanger setting sleeve 650 are decoupled from the apparatus 500. This provides an reliable and efficient method of recovering from an emergency situation such as, for example, where the liner hanger 595, and/or outer collet support member 645, and/or the liner hanger setting sleeve 650 become lodged within the wellbore 2100 and/or the wellbore casing 2105.

Referring to FIGS. 6A to 6C, after positioning the apparatus 500 within the wellbore 2100, the lead wiper 2060 is released from the apparatus 500 by injecting a conventional ball 2400 into an end portion of the lead wiper 2060 using a fluidic material 2405. The fluidic material 2405 is preferably a non-hardenable fluidic material such as, for example, drilling mud.

Referring to FIGS. 7A to 7G, after releasing the lead wiper 2060 from the apparatus 500, a quantity of a hardenable fluidic sealing material 2500 is injected from the apparatus 500 into the wellbore 2100 using the internal passage 2001, the first passage 670, the secondary throat passage 695, the primary throat passage 690, the fourth passage 700, the collet release throat passage 755, the fifth passage 760, the internal passage 2010, the internal passage 2025, the internal passage 2035, and the

internal passage 2055. The hardenable fluidic sealing material 2500 preferably substantially fills the annular space surrounding the liner hanger 595. The hardenable fluidic sealing material 2500 may include any number of conventional hardenable fluidic sealing materials such as, for example, cement or epoxy resin. The hardenable fluidic sealing material preferably includes oil well cement available from Halliburton Energy Services in order to provide an optimal seal for the surrounding formations and structural support for the liner hanger 595 and tubular members 2070. The injection of the hardenable fluidic sealing material 2500 is preferably omitted.

As illustrated in FIG. 7C, prior to the initiation of the radial expansion process, the preload spring 560 exerts a substantially constant axial force on the mandrel 580 and expansion cone 585. In this manner, the expansion cone 585 is maintained in a substantially stationary position prior to the initiation of the radial expansion process. The amount of axial force exerted by the preload spring 560 is preferably varied by varying the length of the spring spacer 555. The axial force exerted by the preload spring 560 on the mandrel 580 and expansion cone 585 preferably ranges from about 500 to 2,000 lbf in order to optimally provide an axial preload force on the expansion cone 585 to ensure metal to metal contact between the outside diameter of the expansion cone 585 and the interior surface of the liner hanger 595. Referring to FIGS. 8A to 8C, after injecting the hardenable fluidic sealing material 2500 out of the apparatus 500 and into the wellbore 2100, the tail wiper 2050 is preferably released from the apparatus 500 by injecting a conventional wiper dart 2600 into the tail wiper 2050 using a fluidic material 2605. The fluidic material 2605 is preferably a non-hardenable fluidic material such as, for example, drilling mud.

Referring to FIGS. 9A to 9H, after releasing the tail wiper 2050 from the apparatus 500, a conventional ball plug 2700 is placed in the primary throat passage 690 by injecting a fluidic material 2705 into the first passage 670. A conventional ball plug 2710 is preferably also placed in the secondary throat passage 695. In this manner, the first passage 670 is optimally fluidicly isolated from the fourth passage 700. The differential pressure across the ball plugs 2700 and/or 2710 preferably ranges from about 0 to 10,000 psi in order to optimally fluidicly isolate the first passage 670 from the fourth passage 700. The fluidic material 2705 is preferably a non-hardenable fluidic material. The fluidic material 2705 preferably includes one or more of the following: drilling mud, water, oil and lubricants.

The injected fluidic material 2705 preferably is conveyed to the crossover valve chamber 685 through the first passage 670, the second passages 675, and the third passage 680. The injected fluidic material 2705 is also preferably conveyed to the force multiplier piston chamber 715 through the first passage 670, the second passages 675, the third passage 680, and the force multiplier supply passages 790. The fluidic material 2705 injected into the crossover valve chambers 685 preferably applies an axial force on one end of the crossover valve members 520. The axial force applied to the crossover valve members 520 by the injected fluidic material 2705 preferably shears the crossover valve shear pins 655. In this manner, one or more of the crossover valve members 520 are displaced in the axial direction thereby fluidicly coupling the fourth passage 700, the inner crossover ports 705, the crossover valve chambers 685, the outer crossover ports 710, and the region outside of the apparatus 500. In this manner, fluidic materials 2715 within the apparatus 500 are conveyed outside of the apparatus. The operating pressure of the fluidic material 2705 is preferably gradually increased after the placement of the sealing ball 2700 and/or the sealing ball 2710 in the primary throat passage 690 and/or the secondary throat passage 695 in order to minimize stress on the apparatus 500. The operating pressure required to displace the crossover valve members 520 preferably ranges from about 500 to 3,000 psi in order to

optimally prevent inadvertent or premature shifting the crossover valve members 520. The one or more of the crossover valve members 520 are preferably displaced when the operating pressure of the fluidic material 2705 is greater than or equal to about 1860 psi. The radial expansion of the liner hanger 595 preferably does not begin until one or more of the crossover valve members 520 are displaced in the axial direction. In this manner, the operation of the apparatus 500 is precisely controlled. Furthermore, the outer crossover ports 710 include controllable variable orifices in order to control the flow rate of the fluidic materials conveyed outside of the apparatus 500. In this manner, the rate of the radial expansion process is optimally controlled.

After displacing one or more of the crossover valve members 520, preferably the operating pressure of the fluidic material 2705 is gradually increased until the radial expansion process begins. In an exemplary embodiment, the radial expansion process begins when the operating pressure of the fluidic material 2705 within the force multiplier piston chamber 715 is greater than about 3200 psi. The operating pressure within the force multiplier piston chamber 715 preferably causes the force multiplier piston 535 to be displaced in the axial direction. The axial displacement of the force multiplier piston 535 preferably causes the force multiplier sleeve 540 to be displaced in the axial direction. Fluidic materials 2720 within the force multiplier exhaust chamber 720 are then preferably exhausted into the fourth passage 700 through the force multiplier exhaust passages 725. In this manner, the differential pressure across the force multiplier piston 535 is maximized. In an exemplary embodiment, the force multiplier piston 535 includes about 11.65 square inches of surface area in order to optimally increase the rate of radial expansion of the liner hanger 595 by the expansion cone 585. The operating pressure within the force multiplier piston chamber 715 preferably ranges from about 1,000 to 10,000 psi during the radial expansion process in order to optimally provide radial expansion of the liner hanger 595.

The axial displacement of the force multiplier sleeve 540 preferably causes the force multiplier sleeve 540 to drive the mandrel 580 and expansion cone 585 in the

axial direction. The axial displacement of the expansion cone 585 radially expands the liner hanger 595 into contact with the preexisting wellbore casing 2105. The operating pressure within the force multiplier piston chamber 715 preferably also drives the mandrel 580 and expansion cone 585 in the axial direction. In this manner, the axial force for axially displacing the mandrel 580 and expansion cone 585 preferably includes the axial force applied by the force multiplier sleeve 540 and the axial force applied by the operating pressure within the force multiplier piston chamber 715. The force multiplier piston 535 and the force multiplier sleeve 540 are omitted and the mandrel 580 and expansion cone 585 are driven solely by fluid pressure.

The radial expansion of the liner hanger 595 preferably causes the top rings 1385 and the lower rings 1390 of the liner hanger 595 to penetrate the interior walls of the preexisting wellbore casing 2105. In this manner, the liner hanger 595 is optimally coupled to the wellbore casing 2105. During the radial expansion of the liner hanger 595, preferably the intermediate sealing members 1395 of the liner hanger 595 fluidicly seal the interface between the radially expanded liner hanger 595 and the interior surface of the wellbore casing 2105.

During the radial expansion process, the dynamic interface between the exterior surface of the expansion cone 585 and the interior surface of the liner hanger 595 is preferably lubricated by lubricants supplied from the body of lubricant 575 through the second lubrication supply passage 800. In this manner, the operational efficiency of the apparatus 500 during the radial expansion process is optimized. The lubricants supplied by the body of lubricant 575 through the second lubrication passage 800 are preferably injected into the dynamic interface between the exterior surface of the expansion cone 585 and the interior surface of the liner hanger 595 substantially as disclosed in one or more of the following: (1) U.S. Patent Application Serial No. 09/440,338, attorney docket number 25791.9.02, filed on 11/15/1999 now United States Patent 6,328,113, which claimed benefit of the filing date of U.S. Provisional Patent Application Serial Number 60/108,558, attorney docket number 25791.9, filed on

11/16/1998, (2) U.S. Patent Application Serial No. 09/454,139, attorney docket number 25791.3.02, filed on 12/31/1999 now United States Patent 6,497,289, which claimed benefit of the filing date of U.S. Provisional Patent Application Serial Number 60/111,293, filed on 12/7/1998, (3) U.S. Patent Application Serial Number 09/502,350, attorney docket number 25791.8.02, filed on 2/10/2000, which claimed the benefit of the filing date of U.S. Provisional Patent Application Serial Number 60/119,611, attorney docket number 25791.8, filed 2/11/1999, (4) U.S. Patent Application Serial Number 09/510,913, attorney docket number 25791.7.02, filed on 2/23/2000, which claimed the benefit of the filing date of U.S. Provisional Patent Application Serial Number 60/121,702, attorney docket number 25791.7, filed on 2/25/1999, (5) U.S. Patent Application Serial Number 09/511,941, attorney docket number 25791.16.02, filed on 2/24/2000 now United States Patent 6,575,240, which claimed the benefit of the filing date of U.S. Provisional Patent Application number 60/121,907, attorney docket number 25791.16, filed 2/26/1999, (6) U.S. Provisional Patent Application Serial Number 60/124,042, attorney docket number 25791.11, filed on 3/11/1999, (7) U.S. Provisional Patent Application Serial Number 60/131,106, attorney docket number 25791.23, filed on 4/26/1999, (8) U.S. Provisional Patent Application Serial Number 60/137,998, attorney docket number 25791.17, filed on 6/7/1999, (9) U.S. Provisional Patent Application Serial Number 60/143,039, attorney docket number 25791.26, filed on 7/9/1999, and (10) U.S. Provisional Patent Application Serial Number 60/146,203, attorney docket number 25791.25, filed on 7/29/1999, the disclosures of which are incorporated by reference.

The expansion cone 585 is reversible. In this manner, if one end of the expansion cone 585 becomes excessively worn, the apparatus 500 can be disassembled and the expansion cone 585 reversed in order to use the un-worn end of the expansion cone 585 to radially expand the liner hanger 595. The expansion cone 585 preferably further includes one or more surface inserts fabricated from materials such as, for example, tungsten carbide, in order to provide an extremely durable material for

contacting the interior surface of the liner hanger 595 during the radial expansion process.

During the radial expansion process, the centralizer 590 preferably centrally positions the mandrel 580 and the expansion cone 585 within the interior of the liner hanger 595. In this manner, the radial expansion process is optimally provided.

During the radial expansion process, fluidic materials 2725 within the second annular chamber 735 are preferably conveyed to the fifth passage 760 through the collet sleeve passages 775, the flow passages 1530, the third annular chamber 750, and the sixth passages 765. In this manner, the axial displacement of the mandrel 580 and the expansion cone 585 are optimized.

Referring to FIGS. 10A to 10E, the radial expansion of the liner hanger 595 is stopped by fluidicly coupling the force multiplier piston chamber 715 with the fourth passage 700. In particular, during the radial expansion process, the continued axial displacement of the mandrel 580 and the expansion cone 585, caused by the injection of the fluidic material 2705, displaces the travel port sealing sleeve 600 and causes the force multiplier piston chamber 715 to be fluidicly coupled to the fourth passage 700 through the expansion cone travel indicator ports 740. The travel port sealing sleeve 600 is preferably removably coupled to the third support member 550 by one or more shear pins. In this manner, accidental movement of the travel port sealing sleeve 600 is prevented.

The fluidic coupling of the force multiplier piston chamber 715 with the fourth passage 700 preferably reduces the operating pressure within the force multiplier piston chamber 715. The reduction in the operating pressure within the force multiplier piston chamber 715 preferably stops the axial displacement of the mandrel 580 and the expansion cone 585. In this manner, the radial expansion of the liner hanger 595 is optimally stopped. The drop in the operating pressure within the force multiplier piston chamber 715 is preferably remotely detected and the injection of the fluidic material 2705 is reduced and/or stopped in order to gradually reduce and/or stop the radial

expansion process. In this manner, the radial expansion process is optimally controlled by sensing the operating pressure within the force multiplier piston chamber 715.

After the completion of the radial expansion process, the hardenable fluidic sealing material 2500 is preferably cured. In this manner, a hard annular outer layer of sealing material is formed in the annular region around the liner hanger 595. The hardenable fluidic sealing material 2500 is preferably omitted.

Referring to FIGS. 11A to 11E, the liner hanger 595, the outer collet support member 645, and the liner hanger setting sleeve 650 are then decoupled from the apparatus 500. The liner hanger 595, the collet retaining adapter 640, the outer collet support member 645, and the liner hanger setting sleeve 650 are preferably decoupled from the apparatus 500 by first displacing the annular support member 2000, the first support member 505, the second support member 515, the force multiplier outer support member 525, the force multiplier inner support member 530, the first coupling 545, the third support member 550, the second coupling 605, the collet mandrel 610, and the collet retaining adapter 640 in the axial direction 2800 relative to the liner hanger 595, the outer collet support member 645, and the liner hanger setting sleeve 650.

In particular, as illustrated in FIG. 11D, the axial displacement of the collet mandrel 610 in the axial direction 2800 preferably displaces the collet retaining sleeve 635 in the axial direction 2800 relative to the collet upsets 1525. In this manner, the collet upsets 1525 are no longer held in the collet slots 1665 by the collet retaining sleeve 635. Furthermore, the axial displacement of the collet mandrel 610 in the axial direction 2800 preferably displaces the first shoulder 1445 in the axial direction 2800 relative to the locking dogs 620. In this manner, the locking dogs 620 lock onto the first shoulder 1445 when the collet mandrel 610 is then displaced in the axial direction 2805. Axial displacement of the collet mandrel of about 1.50 inches preferably displaces the collet retaining sleeve 635 out from under the collet upsets 1525 and also locks the locking dogs 620 onto the first shoulder 1445 of the collet mandrel 610.

Furthermore, the axial displacement of the collet retaining adapter 640 in the axial direction 2800 also preferably displaces the slots 1600 away from the collet upsets 1525.

The liner hanger 595, the collet retaining adapter 640, the outer collet support member 645, and the liner hanger setting sleeve 650 are preferably then decoupled from the apparatus 500 by displacing the annular support member 2000, the first support member 505, the second support member 515, the force multiplier outer support member 525, the force multiplier inner support member 530, the first coupling 545, the third support member 550, the second coupling 605, the collet mandrel 610, and the collet retaining adapter 640 in the axial direction 2805 relative to the liner hanger 595, the outer collet support member 645, and the liner hanger setting sleeve 650. In particular, the subsequent axial displacement of the collet mandrel 610 in the axial direction 2805 preferably pulls and decouples the collet upsets 1525 from the collet slots 1665. The angled outer surfaces 1545 of the collet upsets 1525 preferably facilitate the decoupling process.

If the locking dogs 620 do not lock onto the first shoulder 1445 of the collet mandrel 610, then the annular support member 2000, the first support member 505, the second support member 515, the force multiplier outer support member 525, the force multiplier inner support member 530, the first coupling 545, the third support member 550, the second coupling 605, the collet mandrel 610, and the collet retaining adapter 640 are then displaced back in the axial direction 2800 and rotated. The rotation of the annular support member 2000, the first support member 505, the second support member 515, the force multiplier outer support member 525, the force multiplier inner support member 530, the first coupling 545, the third support member 550, the second coupling 605, the collet mandrel 610, and the collet retaining adapter 640 preferably misaligns the collet slots 1600 and 1665. In this manner, a subsequent displacement of the in the axial direction 2805 pushes the collet upsets 1525 out of the collet slots 1665 in the liner hanger setting sleeve 650. The amount of rotation preferably ranges from

about 5 to 40 degrees. In this manner, the liner hanger 595, the outer collet support member 645, and the liner hanger setting sleeve 650 are then decoupled from the apparatus 500.

The removal of the apparatus 500 from the interior of the radially expanded liner hanger 595 is preferably facilitated by the presence of the body of lubricant 575. In particular, the body of lubricant 575 preferably lubricates the interface between the interior surface of the radially expanded liner hanger 595 and the exterior surface of the expansion cone 585. In this manner, the axial force required to remove the apparatus 500 from the interior of the radially expanded liner hanger 595 is minimized.

Referring to FIGS. 12A to 12C, after the removal of the remaining portions of the apparatus 500, a new section of wellbore casing is provided that preferably includes the liner hanger 595, the outer collet support member 645, the liner hanger setting sleeve 650, the tubular members 2070 and an outer annular layer of cured material 2900.

The interior of the radially expanded liner hanger 595 is preferably used as a polished bore receptacle ("PBR"). The interior of the radially expanded liner hanger 595 is preferably machined and then used as a PBR. The first end 1350 of the liner hanger 595 is threaded and coupled to a PBR.

All surfaces of the apparatus 500 that provide a dynamic seal are preferably nickel plated in order to provide optimal wear resistance.

Referring to FIGS. 13A to 13G, an alternative embodiment of an apparatus 3000 for forming or repairing a wellbore casing, pipeline or structural support will be described. The apparatus 3000 preferably includes the first support member 505, the debris shield 510, the second support member 515, the one or more crossover valve members 520, the force multiplier outer support member 525, the force multiplier inner support member 530, the force multiplier piston 535, the force multiplier sleeve 540, the first coupling 545, the third support member 550, the spring spacer 555, the preload spring 560, the lubrication fitting 565, the lubrication packer sleeve 570, the body of

lubricant 575, the mandrel 580, the expansion cone 585, the centralizer 590, the liner hanger 595, the travel port sealing sleeve 600, the second coupling 605, the collet mandrel 610, the load transfer sleeve 615, the one or more locking dogs 620, the locking dog retainer 622, the collet assembly 625, the collet retaining sleeve 635, the collet retaining adapter 640, the outer collet support member 645, the liner hanger setting sleeve 650, the one or more crossover valve shear pins 655, the one or more collet retaining sleeve shear pins 665, the first passage 670, the one or more second passages 675, the third passage 680, the one or more crossover valve chambers 685, the primary throat passage 690, the secondary throat passage 695, the fourth passage 700, the one or more inner crossover ports 705, the one or more outer crossover ports 710, the force multiplier piston chamber 715, the force multiplier exhaust chamber 720, the one or more force multiplier exhaust passages 725, the second annular chamber 735, the one or more expansion cone travel indicator ports 740, the one or more collet release ports 745, the third annular chamber 750, the collet release throat passage 755, the fifth passage 760, the one or more sixth passages 765, the one or more seventh passages 770, the one or more collet sleeve passages 775, the one or more force multiplier supply passages 790, the first lubrication supply passage 795, the second lubrication supply passage 800, the collet sleeve release chamber 805, and a standoff adaptor 3005.

Except as described below, the design and operation of the first support member 505, the debris shield 510, the second support member 515, the one or more crossover valve members 520, the force multiplier outer support member 525, the force multiplier inner support member 530, the force multiplier piston 535, the force multiplier sleeve 540, the first coupling 545, the third support member 550, the spring spacer 555, the preload spring 560, the lubrication fitting 565, the lubrication packer sleeve 570, the body of lubricant 575, the mandrel 580, the expansion cone 585, the centralizer 590, the liner hanger 595, the travel port sealing sleeve 600, the second coupling 605, the collet mandrel 610, the load transfer sleeve 615, the one or more locking dogs 620, the

locking dog retainer 622, the collet assembly 625, the collet retaining sleeve 635, the collet retaining adapter 640, the outer collet support member 645, the liner hanger setting sleeve 650, the one or more crossover valve shear pins 655, the one or more collet retaining sleeve shear pins 665, the first passage 670, the one or more second passages 675, the third passage 680, the one or more crossover valve chambers 685, the primary throat passage 690, the secondary throat passage 695, the fourth passage 700, the one or more inner crossover ports 705, the one or more outer crossover ports 710, the force multiplier piston chamber 715, the force multiplier exhaust chamber 720, the one or more force multiplier exhaust passages 725, the second annular chamber 735, the one or more expansion cone travel indicator ports 740, the one or more collet release ports 745, the third annular chamber 750, the collet release throat passage 755, the fifth passage 760, the one or more sixth passages 765, the one or more seventh passages 770, the one or more collet sleeve passages 775, the one or more force multiplier supply passages 790, the first lubrication supply passage 795, the second lubrication supply passage 800, and the collet sleeve release chamber 805 of the apparatus 3000 are preferably provided as described above with reference to the apparatus 500 in FIGS. 2A to 12C.

Referring to FIGS. 13A to 13C, the standoff adaptor 3005 is coupled to the first end 1005 of the first support member 505. The standoff adaptor 3005 preferably has a substantially annular cross-section. The standoff adaptor 3005 may be fabricated from any number of conventional commercially available materials. The standoff adaptor 3005 is fabricated from alloy steel having a minimum yield strength of about 75,000 to 140,000 psi in order to optimally provide high tensile strength and resistance to abrasion and fluid erosion. The standoff adaptor 3005 preferably includes a first end 3010, a second end 3015, an intermediate portion 3020, a first threaded portion 3025, one or more slots 3030, and a second threaded portion 3035.

The first end 3010 of the standoff adaptor 3005 preferably includes the first threaded portion 3025. The first threaded portion 3025 is preferably adapted to be

removably coupled to a conventional tubular support member. The first threaded portion 3025 may be any number of conventional threaded portions. The first threaded portion 3025 is preferably a 4 ½" API IF JT BOX thread in order to optimally provide tensile strength.

The intermediate portion 3020 of the standoff adaptor 3005 preferably includes the slots 3030. The outside diameter of the intermediate portion 3020 of the standoff adaptor 3005 is preferably greater than the outside diameter of the liner hanger 595 in order to optimally protect the sealing members 1395, and the top and bottom rings, 1380 and 1390, from abrasion when positioning and/or rotating the apparatus 3000 within a wellbore, or other tubular member. The intermediate portion 3020 of the standoff adaptor 3005 preferably includes a plurality of axial slots 3030 equally positioned about the circumference of the intermediate portion 3020 in order to optimally permit wellbore fluids and other materials to be conveyed along the outside surface of the apparatus 3000.

The second end of the standoff adaptor 3005 preferably includes the second threaded portion 3035. The second threaded portion 3035 is preferably adapted to be removably coupled to the first threaded portion 1015 of the first end 1005 of the first support member 505. The second threaded portion 3035 may be any number of conventional threaded portions. The second threaded portion 3035 is preferably a 4 ½" API IF JT PIN thread in order to optimally provide tensile strength.

Referring to FIGS. 13D and 13E, in the apparatus 3000, the second end 1360 of the liner hanger 595 is preferably coupled to the first end 1620 of the outer collet support member 645 using a threaded connection 3040. The threaded connection 3040 is preferably adapted to provide a threaded connection having a primary metal-to-metal seal 3045a and a secondary metal-to-metal seal 3045b in order to optimally provide a fluidic seal. The threaded connection 3040 is preferably a DS HST threaded connection available from Halliburton Energy Services in order to optimally provide high tensile strength and a fluidic seal for high operating temperatures.

Referring to FIGS. 13D and 13F, in the apparatus 3000, the second end 1625 of the outer collet support member 645 is preferably coupled to the first end 1650 of the liner hanger setting sleeve 650 using a substantially permanent connection 3050. In this manner, the tensile strength of the connection between the second end 1625 of the outer collet support member 645 and the first end 1650 of the liner hanger setting sleeve 650 is optimized. The permanent connection 3050 preferably includes a threaded connection 3055 and a welded connection 3060. In this manner, the tensile strength of the connection between the second end 1625 of the outer collet support member 645 and the first end 1650 of the liner hanger setting sleeve 650 is optimized.

Referring to FIGS. 13D, 13E and 13F, in the apparatus 3000, the liner hanger setting sleeve 650 further preferably includes an intermediate portion 3065 having one or more axial slots 3070. The outside diameter of the intermediate portion 3065 of the liner hanger setting sleeve 650 is preferably greater than the outside diameter of the liner hanger 595 in order to protect the sealing elements 1395 and the top and bottom rings, 1385 and 1390, from abrasion when positioning and/or rotating the apparatus 3000 within a wellbore casing or other tubular member. The intermediate portion 3065 of the liner hanger setting sleeve 650 preferably includes a plurality of axial slots 3070 equally positioned about the circumference of the intermediate portion 3065 in order to optimally permit wellbore fluids and other materials to be conveyed along the outside surface of the apparatus 3000.

The apparatus 500 and 3000 are preferably used to fabricate and/or repair a wellbore casing, a pipeline, or a structural support. In several other alternative embodiments, the apparatus 500 and 3000 are used to fabricate a wellbore casing, pipeline, or structural support including a plurality of concentric tubular members coupled to a preexisting tubular member.

TABLE FOR CONVERSION TO METRIC UNITS

0 to 650 gallons/minute and 0 to 10,000 psi (0 to 2,460.51767 litres and 0 to 689.476 bar)

1000 to 10000 psi (68.95 to 689.5 bar)

75,000 to 140,000 psi (5,171.06796 to 9,652.660192 bar)

4 ½" (11.43 centimetres)

0.005 to 0.010 inches (0.0127 to 0.0254 centimetres)

500 to 2000 lbf/in (0.2394013 to 0.9576052 bar)

0.05 to 0.025 inches (0.127 to 0.0635 centimetres)

0.06 inches (0.1524 centimetres)

5 to 12 feet (1.524 metre to 3.6576 metre)

40,000 to 125,000 psi (5,171.06796 to 8,618.4466 bar)

0.12 to 2 inches (0.3048 to 5.08 centimetres)

8 to 20 inches (20.32 to 50.8 centimetres)

0.25 to 2 inches (0.635 to 5.08 centimetres)

0.10 to 2.00 inches (0.254 to 5.08 centimetres)

0 to 10,000 psi and 0 to 650 gallons/minute (0 to 689.476 bar and 0 to 2,460.51767 litres)

0 to 10,000 psi and 0 to 200 gallons/minute (0 to 689.476 bar and 0 to 757.08236 litres)

0 to 10,000 psi and 0 to 50 gallons/minute (0 to 689.476 bar and 0 to 189.27059 litres)

0 to 10,000 psi (0 to 689.476 bar)

1,000 to 3,000 psi (68.9475728 to 206.8427184 bar)

1650 psi (113.7634951 bar)

500 to 3,000 psi (34.4737864 to 206.8427184 bar)

3200 psi (220.632233 bar)

CLAIMS

1. An apparatus, comprising:
a support member;
a tubular member coupled to the support member;
an annular expansion cone movably coupled to the support member and the tubular member and positioned within the tubular member for radially expanding the tubular member; and
a preload assembly for applying an axial force to the annular expansion cone, including:
a compressed spring coupled to the support member for applying the axial force to the annular expansion cone; and
a spacer coupled to the support member for controlling the amount of spring compression.

2. The apparatus of claim 1 wherein the spacer comprises a substantially annular cross-section.

3. The apparatus of claim 1, wherein the spacer comprises alloy steel.

4. The apparatus of claim 3, wherein the steel comprises a minimum yield strength ranging from 5,171.06796 to 9,652.660192 bar (75,000 to 140,000 psi).

5. The apparatus of claim 1, wherein the spacer comprises a material that provides high strength and resistance to abrasion and fluid erosion.

6. The apparatus of claim 1, wherein the spring comprises an alloy selected from the group consisting of chromium-vanadium and chromium-silicon.

7. The apparatus of claim 1, wherein the spring provides a force to seal the interface between the expansion cone and the tubular member.

8. The apparatus of claim 1, wherein the spring comprises a spring rate ranging from 0.2394013 to 0.9576052 bar (500 to 2000 lbf/in).